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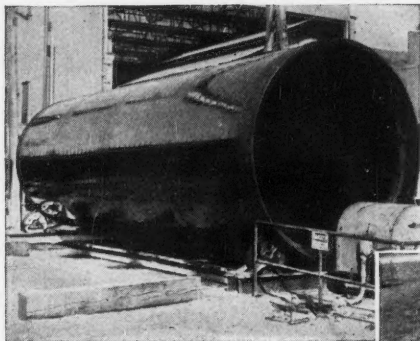
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# **Corrosion—the Great Destroyer**

*By D. J. Fergus*

Research Engineer, The Cleveland Heater Co., Cleveland, Ohio

SINCE the first day that man, through his ingenuity, contrived to reduce metallic ores to useful engineering materials, he has been constantly confronted and challenged by those fundamental laws of nature that, through the process of corrosion tend to convert those useful metals back to the state in which they were first discovered.

Today losses incurred by mankind from metal wastage through the process of corrosion have reached enormous proportions. Some estimates in dollar value alone are on the order of billions of dollars annually. More serious, however, than any monetary consideration, are the injuries and loss of life suffered by many through accidents which can be traced directly to some corrosion phenomena.

With the gradual rise in standards of living, many useful devices have come within the financial reach of the lower income groups. One of these conveniences, storage water heating employing a galvanized steel storage tank, has come to be regarded as a necessity in wholesome and healthful living by a majority of families. In many instances, these tanks are rendered useless by corrosion even though 99.5 percent of the original metal remains intact.

These losses in the aggregate make corrosion of hot water storage tanks a tremendous economic burden.

Through technological advances in home laundering equipment, the demand for clear rust-free hot water has increased by leaps and bounds, until today the corrosion of hot water storage tanks has become one of the most serious domestic problems confronting the general public.

The situation has of late become so acute that a tremendous responsibility has been placed on the manufacturers of storage water heaters and tanks. In an effort to increase the useful life of the tank and to create greater customer satisfaction these manufacturers have initiated and financially supported research and development projects throughout the country. Many outstanding corrosion experts have been consulted and the aid of municipal water works divisions have been enlisted. Despite all efforts, the corrosion problem up to the present time has been essentially the same as it was five to ten years ago.

What causes corrosion, and to be more specific, what causes corrosion in a hot water storage tank? Many theories have been advanced, each of which explains some particular phenomenon more satisfactorily than the others. The theory of

TABLE 1  
ELECTROMOTIVE FORCE SERIES OF ELEMENTS  
Standard Electrode Potentials at 25° C.

Element	Potential	Element	Potential	Element	Potential
Lithium +	2.9595	Iron ++	0.441	Iodine —	-0.5345
Rubidium +	2.9259	*Cadmium ++	0.401	*Tellurium +++	-0.558
Potassium +	2.9241	*Indium ++	0.336	Silver +	-0.7978
*Strontium ++	2.92	*Thallium ++	0.330	Mercury ++	-0.7986
*Barium ++	2.90	Cobalt ++	0.278	*Lead +++	-0.80
*Calcium ++	2.87	Nickel ++	0.231	*Palladium ++	-0.820
Sodium +	2.7146	Tin ++	0.136	*Platinum Pt	-0.863
*Magnesium ++	2.40	Lead ++	0.122	Bromine —	-1.0648
*Aluminum ++	1.7	*Iron +++	0.045	Chlorine —	-1.3583
*Beryllium ++	1.69	Hydrogen +	0.0000	*Gold +++	-1.360
*Uranium +++	1.40	*Antimony ++	-0.10	*Silver +	-1.50
*Manganese ++	1.10	*Bismuth ++	-0.226	*Fluorine —	-1.90
*Tellurium —	0.827	*Arsenic +++	-0.30		
Zinc ++	0.7618	Copper ++	-0.344		
Chromium ++	0.557	*Oxygen OH —	-0.397		
*Sulfur —	0.51	Polonium +++	-0.40		
*Gallium +++	0.50	Copper +	-0.470		

Table reproduced from the Handbook of Chemistry and Physics, 29th Edition, by permission of the publisher, The Chemical Rubber Co., Cleveland, Ohio.

\* These values are doubtful but they indicate the relative activity of the elements and are therefore included.

widest applicability and acceptance, however, is the electro-chemical theory of corrosion.

By definition, electro-chemistry (electro-chemical is the adjective form) is the science of the relation of electricity to chemical changes. The electro-chemical theory of corrosion is based on the Nernst theory of electrolytic solution pressure and can be briefly stated thus: "When a metal is immersed in water, there is a tendency for the atoms of the metal to become ions and go into solution, leaving their electrons on the metal, thus giving the metal a negative charge." This tendency is somewhat the same as that of a liquid to assume the gaseous state, and accordingly, Nernst has called it the electrolytic solution pressure. Each metal has its own characteristic electrolytic solution pressure, and the numerical values for these pressures of various metals may vary tremendously. For instance, the solution pressure of magnesium is  $1.1 \times 10^{43}$  atmospheres, whereas that of platinum is  $1.0 \times 10^{36}$  atmospheres.

In addition to the electrolytic solu-

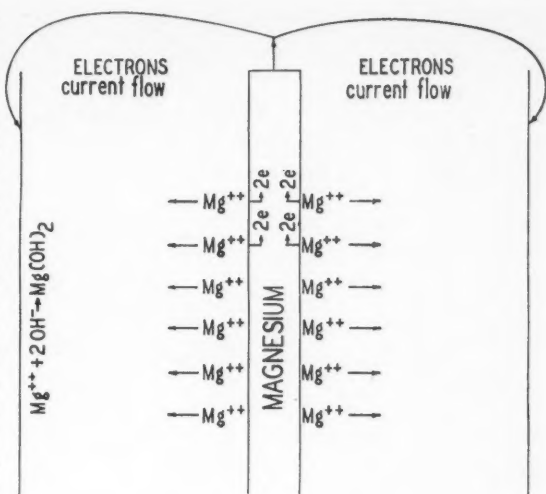
tion pressure, there is another force called osmotic pressure which tends to force the ions from solution onto the metal surface thereby giving the metal a positive electrical charge. However, with metals like zinc and magnesium and others toward the electro-negative end of the electromotive series as listed in Table 1, the electrolytic solution pressure exceeds the osmotic pressure, and the metal, when immersed in a solution of its own ions, is negatively charged. With metals toward the positive end of the series, the reverse is true; the osmotic pressure exceeds the electrolytic solution pressure and the metal receives a positive charge. This is the basis for the theory of electro-chemical corrosion.

### Voltaic Cells

In the early experiments in electro-chemistry, the only sources of electrical energy were discharges from electrostatic machines. Because such machines provided very small quantities of electricity, a search for better sources was made, and the Voltaic cell was developed. Voltaic cells are cells in which chemical

changes of matter produce electrical energy. By extended experiments with voltaic cells, the relationship of various metals as to their relative nobility was determined as set forth in the table on the electromotive series. As one reads down the list the relative nobility increases. In general, the more noble the metal the less likely it is to corrode. Under certain conditions, a metal will replace another that is below it (more noble) in the electromotive series. Thus, a piece of iron dipped into a copper sulphate solution will become coated with copper. The iron takes the place of the copper in the solution, and an equivalent amount of copper plates out on the iron. When all the iron has been coated with copper, further action is stopped. Likewise, zinc will replace iron in solution, nickel will replace copper, etc.

A term also widely used in the corrosion field is galvanic corrosion. By definition, "galvanic" is of, or relating to direct current electricity. A voltaic cell is also called a galvanic cell. Galvanic cells may be made up of two or more elements, one serving as an anode and the other as a cathode. In the presence of a suitable electrolyte, current will flow in the circuit when an electrical



### REACTIONS AT CATHODE OR TANK WALL

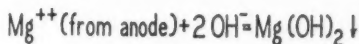
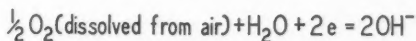


Figure 1.

connection is made between the anode and the cathode.

### Anodes and Cathodes

It may be well at this point to define the words "anode" and "cathode." The anode is the element at which an oxidation process occurs; the cathode is the element at which a reduction process occurs. Oxidation, on the basis of the electron theory, is a process in which an element loses electrons and, conversely, reduction is the process in which an element gains electrons. Therefore, when one speaks of galvanic corro-

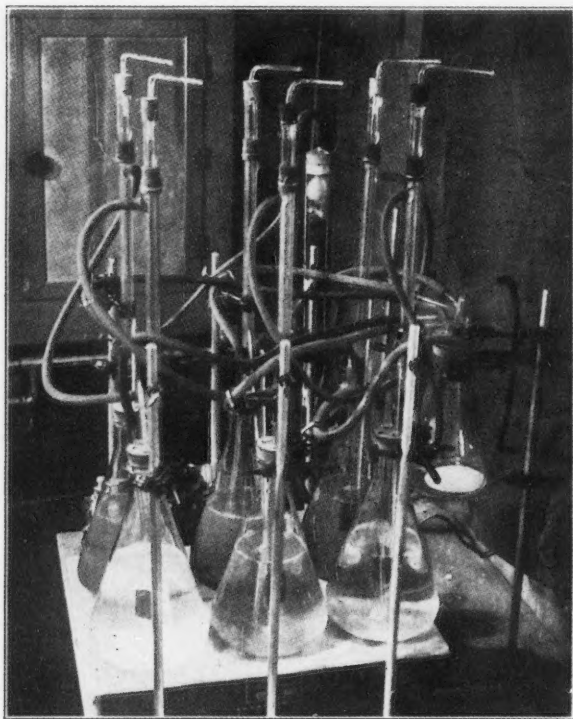


Figure 2—Test apparatus for determining current efficiency of magnesium and magnesium alloys before choosing alloy used in protecting galvanized tanks.

sion with respect to metals, one quite naturally can assume that there is an anode and a cathode, and that the anode will be the metal that is consumed by the environment. In other words, corrosion will take place at the anode. Conversely, corrosion will not occur at the cathode.

For purposes of illustration, but, however, not for direct comparison, the mechanics of a simple galvanic cell, the ordinary flashlight battery, will be briefly discussed. It consists of a zinc container serving as an anode, a carbon rod, serving as a cathode, which is electrically in-

sulated from the zinc, an electrolyte in paste form, containing zinc and ammonia chlorides, and manganese dioxide which is located in the paste next to the carbon rod, serving as a depolarizer. When electrical contact is made between the zinc container and the carbon rod, current will flow and will continue to flow for some time; however, if it were not for the presence of the manganese dioxide at and near the carbon rod, hydrogen would quickly collect at the carbon cathode to such an extent that the battery would not have enough voltage to light the flashlight bulb. This is one form of po-

larization. The hydrogen, if allowed to collect at the cathode, would increase the internal resistance of the battery and would also tend to serve as an electrode, both of which actions would result in a much lower voltage. The manganese dioxide, however, reacts with the hydrogen to form water and manganese oxide. It therefore follows that in order to maintain high current output a depolarizer at the cathode is necessary.

From the foregoing discussion it is quite evident that the initiation of electro-chemical corrosion is dependent on the presence of galvanic or

**TABLE 2**  
**DISSOLVED OXYGEN (p.p.m)**

Days of Operation	Unprotected Tank No. 5	Elco Protected Tank No. 10	Tap Water
7	2.5	1.8	9.2
14	.....	1.8	11.6
24	.....	1.0	12.6
42	0.2	.....	12.6
58	.....	2.6	15.7
77	0.8	.....	15.7
94	.....	9.3	16.9
115	0.7	.....	16.9
126	.....	10.79	15.28
151	0.6	.....	15.28
179	.....	10.54	11.81
200	0.95	.....	12.75

so-called "local" cells, and the continuous operation of the galvanic cells at high rates is dependent on the presence of a depolarizer.

A clear, concise answer can now be made to the question, "What causes corrosion in a hot water storage tank?" The two most important and also necessary factors are the existence of local galvanic cells on the inner walls of the tank (there is no such thing as a chemically pure surface in such vessels), and a depolarizer in the form of dissolved oxygen, some of which all natural waters contain. Suffice to say that most chemical reactions are speeded up by increase in temperature and sufficient oxygen is always pres-

ent (due to frequent draws) to prevent polarization by collection of hydrogen at the cathodes. After corrosion is initiated at the anodes of the local cells, other factors may enter the picture. In the case where an insoluble corrosion product is formed at the anode of the local cell, such as a rust tubercle, oxygen concentration cells add their weight in speeding up the corrosion process.

The problem of internal corrosion in galvanized steel hot water storage

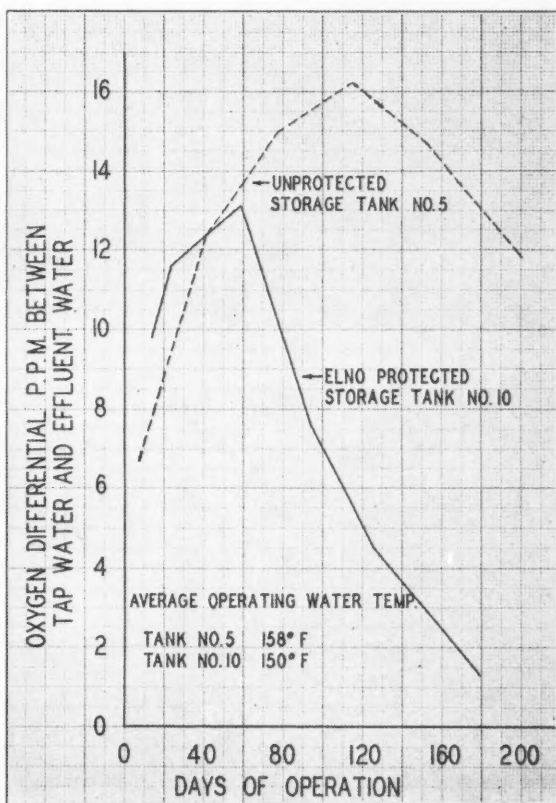
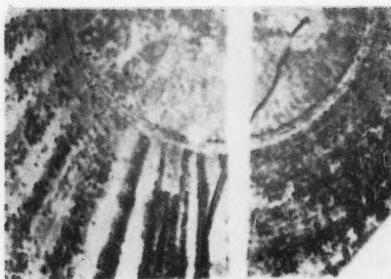


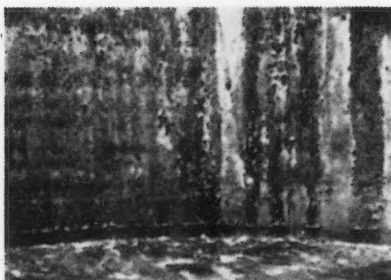
Figure 3.

**TANK NO. 5****(Non-Galvanized—Unprotected)**

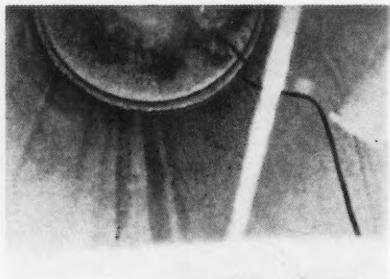
VIEW OF WALL AT TOP



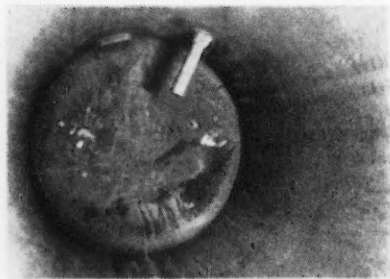
VIEW OF BOTTOM



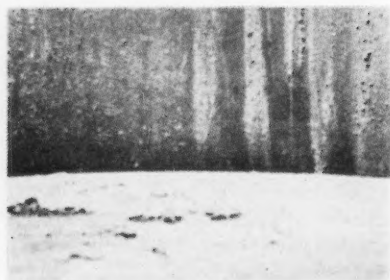
VIEW OF WALL AT BOTTOM

**TANK NO. 10****(Non-Galvanized—"Elno" Protected)**

VIEW OF WALL AT TOP



VIEW OF BOTTOM



VIEW OF WALL AT BOTTOM

Figure 4—Views of unprotected tank (left), and protected tank (right). Unprotected tank shows results of corrosion after six months of service with water temperature at 200° F. Note severe corrosion and dark tubercles: "Elno" protected tank at right operated under same conditions as Tank No. 5. Note that though corrosion did start, it was halted by white film covering tubercles.



tanks can now be simplified and stated as follows:

1. The two essential factors for electro-chemical corrosion are always present in any galvanized steel hot water storage tank.
2. For all practical purposes, the elimination of either factor will prevent corrosion or at least lower the rate to such an extent that under normal conditions it would take many, many years to become even noticeable.

From this working basis, then, one can intelligently approach the corrosion problem of galvanized steel hot water storage tanks with a fair chance of solving it.

In past years many efforts were made to eliminate oxygen from natural water and thereby prevent corrosion in hot water storage tanks. On an experimental scale, where all oxygen was removed, it has been proved that corrosion is prevented. Oxygen can be removed from water by pre-heating it in an open vessel or by reducing the pressure to some value less than atmospheric pressure or by chemical treatment. To the author's knowledge, however, no economical method has yet been evolved that can be applied to the simple hot water storage tank and still keep consumer costs within reasonable bounds.

### **Sacrificial Corrosion**

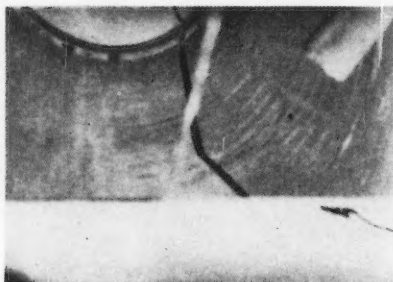
It has long been known that excellent protection of metals can be obtained through either the sacrificial corrosion of a less noble metal or by applying an electric current to the system. The galvanized steel tank is an outstanding example. The dipping of the steel into molten zinc,

resulting in an adherent coating of zinc and iron-zinc compounds, derives its name from the Italian physiologist, Galvani, whose researches led to the first clarified exposition of the generation and conduction of electricity. Zinc, less noble than iron, is sacrificed and the iron protected. The best grade of commercially pure zinc itself contains small amounts of impurities and, even though the greatest care can be exercised in the galvanizing process, it is humanly impossible to prevent the formation of local galvanic cells on the walls of storage tanks or, as a matter of fact, on any galvanized article. So, once the corrosion process has started it is not likely to die a natural death. Too, there are practical limitations as to how thick a zinc coating can be applied to a storage tank. Thus, at isolated areas, zinc will be rapidly used up until the iron is exposed. Zinc can protect iron only over short distances, consequently, red rust soon appears, followed by perforation of the tank wall.

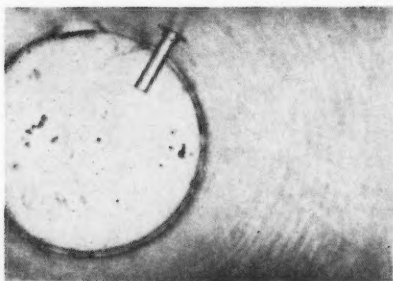
If the equipment to be protected is made the cathode of a cell in which the anode is insoluble, protection can be assured. In this case it is only necessary to obtain a minimum electric current density, commonly called the protective current density, at the surface being protected. The current density required depends primarily upon the nature of the solution and to some extent upon the physical condition of the metal to which it is applied. Generally, in a neutral solution, a relatively low current density is enough to give complete protection.

The protective technique of gal-

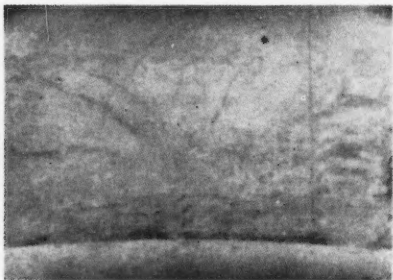
### GALVANIZED TANK Photographed When New



VIEW OF WALL AT TOP

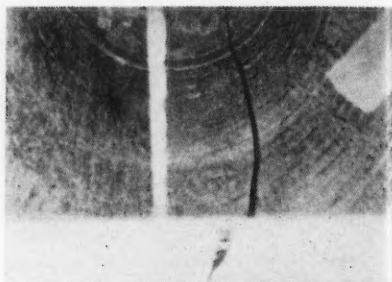


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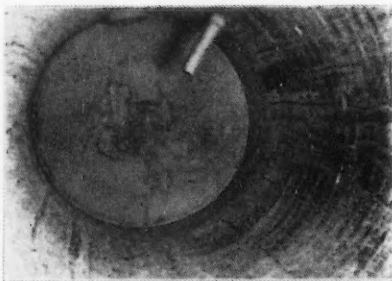


VIEW OF WALL AT BOTTOM

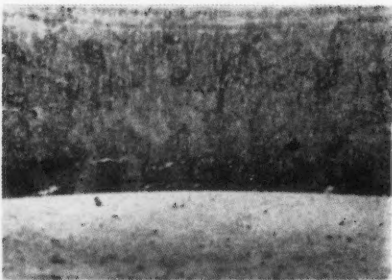
### SAME TANK after 6 months of Service with an "Elno" Protector



VIEW OF WALL AT TOP



VIEW OF BOTTOM



VIEW OF WALL AT BOTTOM

Figure 5—Three views (left) of a new galvanized steel hot water storage tank photographed before the start of accelerated operation test to check action of "Elno" Protector. Right shows same tank photographed after six months of operation at 200° F. No corrosion found or expected to occur during life of the anode.

vanic or cathodic type is relatively safe to use. It tends to reduce the probability of corrosion starting, without in any way increasing the intensity once corrosion has begun. Consequently, no troubles due to rapid pitting are experienced when using current densities lower than that which gives complete protection. Generally, the question of whether or not to apply this type of protection is purely an economic one. Oftentime, the cost of electricity or of the sacrificial metal is greater than the saving involved in the protected metal.

#### Local Galvanic Cells

The local galvanic cells on the internal walls of the tank depend on current flow for corrosive action at the anode. It follows, therefore, that if the internal walls of the tank can be made a cathode by some suitable means, then a current will be produced which flows in opposition to the corrosion current set up in the local galvanic cells. If the amount of current so produced is equal to or greater than the corrosion currents, then complete protection against corrosion will be achieved.

#### Use of Magnesium

The use of magnesium or magnesium alloys as an anode in a hot water storage tank has unique advantages. Magnesium is relatively insoluble in water and has a high electrode potential. It is one of the most abundant metals and, due to the recognition of its importance during the past war, a large capacity for its production has resulted. Although it is still a relatively expensive metal when compared to some of the more common metals such as iron, the price range today makes it a suitable material for consumer

goods in those instances where large savings accrue to the consumer. It provides a solution to the mitigation and ultimate elimination of internal corrosion in galvanized hot water storage tanks.

When a magnesium rod is inserted in a galvanized tank filled with water and electrical contact is made between the magnesium and the tank, we have essentially what is called a wet cell. The magnesium serves as an anode, the tank serves as a cathode, and the water is the electrolyte. Magnesium atoms will lose their electrons and go into solution as ions. The electrons flow (current) from the magnesium to the tank by way of the electrical connections. The magnesium ions will travel through the water to the tank walls (see Figure 1), and will precipitate as magnesium hydroxide ( $Mg(OH)_2$ ). Thus magnesium not only has a high electrode potential, but also has the ability to generate a protective film on the tank walls.

There are many today who insist that, in those natural waters deficient in calcium and magnesium ions, internal corrosion of storage tanks will be aggravated because the water does not have good film-forming qualities. In this instance, the magnesium anode will supply a sufficient quantity of the necessary ions.

Acid waters are also considered to be highly corrosive insofar as hot water storage tanks are concerned. Once again magnesium displays its versatility. Magnesium hydroxide formed by the cell action will neutralize acid waters.

Before attempting full scale tests on 30-gallon capacity hot water storage tanks, there was one more very



Figure 6—Tank No. 10, wall at bottom, when installed.

important consideration that required investigation. To determine whether this type of corrosion inhibition would be completely practical from the economical point of view, some knowledge was needed as to how long a given amount of magnesium would last when installed as an anode in a hot water storage tank.

Theoretically, if the average current flow is known, the amount of magnesium that is used or sacrificed in protecting the tank can be calculated from its electro-chemical equivalent, which is derived from Faraday's Law. However, due to minute amounts of impurities, electro-chemical or galvanic corrosion will take place on the magnesium itself, and the metal lost in this way plays no useful part in protecting

the walls of a storage tank. As a direct result, the life of the magnesium anode would be seriously shortened if much of this type of metal wastage were allowed. It therefore follows that "current efficiencies" of magnesium and its alloys had to be determined in order to know whether or not the cost of this type of corrosion prevention was prohibitive.

A number of laboratory tests were made in which magnesium and magnesium alloys and galvanized steel cells were set up under conditions similar to those encountered in hot water storage tanks, with the exception of pressure. These tests were conducted at atmospheric pressure. See Figure 2. From current records and monthly determinations of loss in weight of the magnesium anodes,

"current efficiency" values were calculated. That material which showed the highest "current efficiency," 79.8 percent, was then selected for test in conventional hot water storage tank installations.

### Accelerated Tests

Generally, corrosion and corrosion testing are inherently long term processes. Some corrosion tests are not completed until after periods of 5, 10, 15 and even 20 years. For purposes of speed and in order to satisfy public demand, "black iron" or ungalvanized steel tanks were set up side by side with galvanized tanks. Water temperatures were increased from a normal range of 140-150° F., to a temperature range of 200-210° F., to intensify any corrosion process that might occur. Daily draws of 25 gallons, 15 gallons in the morning and 10 gallons in the afternoon, and monthly analyses of effluent water were made.

Over a long period of time, it has been found that the amount of dissolved oxygen that disappears or is used up while the water remains in the tank is an excellent criterion as to how much corrosion is taking place. It does not, however, distinguish between localized and general corrosive attack. Nevertheless, experience has led to a high regard for this test, for it tells a story that the unaided eye cannot see.

In Figure 3 are curves plotted from data found in Table 2. Both tanks represented by these curves are "black iron," or ungalvanized steel tanks. The amount of oxygen used up in the corrosion processes has been plotted against time. The curve of the unprotected tank changes in direction after 120 days of operation toward a lower value

in amount of oxygen used up. However, a glance at Table 2 will show that it is only a reflection of changes in the total amount of dissolved oxygen in the tap water. The amount of oxygen found in tap water will be low in the summer and high in the winter, due to the fact that the solubility of oxygen in water increases with decreasing temperatures. It should also be kept in mind that the curve representing the protected tank represents a corrosive process which has been intentionally introduced, and the lowering of the amount of oxygen used up in the tank is primarily due to the film that has been generated at the cathode, the tank walls, which has the effect of screening the cathode from the dissolved oxygen, thereby diminishing the maximum rate at which oxygen dissolution can occur.

In Figure 4 three views, top, bottom and wall at the bottom, for both Tanks No. 5 and No. 10 are shown. These photographs were taken after six months operation of each tank under almost identical conditions. Tank No. 5 shows a very serious state of corrosion, and was removed from the test line shortly after these pictures were taken because it was no longer useful for test purposes. Tank No. 10 does show some tuberculation, which occurred early in the test and is reflected in its oxygen consumption curve found in Figure 3. Since then, however, further growth has been retarded and in the meanwhile, the tubercles have become coated with a white film due to the electrochemical action of the magnesium anode. Figure 6 is shown because it presents a rather interesting study

in electro-chemical corrosion. This picture is the same view as No. 3 of tank 10 in Figure 4 at the time of installation. In the vicinity of the vertical welded seam of the tank, which is located at the extreme right, are light and dark areas where iron oxide or mill scale has been loosened and flaked off during forming of the shell of the tank. All corrosion experts are agreed that this condition is very conducive to electro-chemical corrosion. The iron exposed by the flaking off of the mill scale will be anodic to the iron oxide, or mill scale that remains attached. It is interesting to note that these areas are those which contain the largest number of tubercles after six months operation and also very interesting to note that these areas are receiving the greatest share of attention from the magnesium anode in its generation of protective film. Since the first month of operation, the tubercles have not increased in

size and are becoming whiter and whiter from the deposition of magnesium hydroxide and calcium carbonate.

Figure 5 shows three different views of a galvanized hot water storage tank before its installation, and the same three views after six months of accelerated operation at the excessive temperature of 200° F. As long as any of the magnesium anode remains in electrical contact with the tank, no corrosion is expected to occur on the walls of the tank.

### Research Continuing

Development work on this project is continuing, and is also being expanded so that maximum protection against electro-chemical corrosion in hot water storage tanks can be realized by the user, no matter which of the various types of natural waters found in this country is used in the tank.

### Conclusions

1. A practical solution to the problem of internal corrosion of galvanized steel hot water storage tanks has been found through intensive research based on the electro-chemical theory of corrosion.

2. It has been determined that magnesium and magnesium alloys when used for anodic protection of tanks, are versatile in that they not only have a high electrode potential for the production of anti-corrosion currents, but also generate protective films on the tank walls.

3. It has been demonstrated that, in tanks employing magnesium or magnesium alloys in the manner outlined, the magnesium hydroxide formed will neutralize acid water.

4. In extensive tests conducted under highly intensified corrosive conditions, magnesium and magnesium alloys, used as expendable anodes, have effectively displayed their ability to mitigate against internal corrosion of galvanized steel hot water tanks.



## Economic Aspects of Corrosion Problems

By F. A. Rohrman

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WHEN man reduces metals from the ores, he abruptly reverses one of nature's fundamental tendencies. All metals have a more or less tendency to tarnish, rust, or go into solution. Reduction is in opposition to this tendency, which may be called oxidation. Once a metal has been reduced from its ore, all of nature's forces combine to regain and recapture the original state of the metal. Slow as this degradation may be, it proceeds steadily and relentlessly until the metal is again in compound form. Unfortunately, those metals most useful to man for structural purposes are those so highly susceptible to these destructive forces. It is for these reasons that man has constantly been plagued by the evils of rust or corrosion on the metals he has worked so hard to gain.

Earliest man was cognizant of the undesirable qualities of corrosion. St. Matthew in the sixth chapter and nineteenth verse of the New Testament refers to earth as a place, "Where moth and rust doth corrupt." In the general Epistle of James, fifth chapter and third verse, is the quotation, "Your gold and silver is cankered: and the rust of them shall be a witness against you,—" Pliny, the great Roman historian, made several references to corrosion.

In fact, the Romans were so familiar with leaded paints for painting iron that they even resorted to the sale of adulterated paints. Chaucer, hundreds of years ago, stated, "If gold ruste, what shall iren do?" It is evident, then, that man considered corrosion as one of his many banes, which he accepted and bore as inevitable.

The past hundred years has seen the advent and use of many more new metals, and the intensified and extended use of those already known. And it has been in only these comparatively recent times that concerted efforts have been made to prevent, combat, and retard corrosion. The increased use of iron and steel, aluminum, zinc, alloys of copper, etc., along with more severe operating conditions made corrosion prevention a chief factor in choosing materials of construction. The past few years have seen thousands of new chemical agents processed under higher and higher temperatures and pressures, and in larger and larger scales of production. Steam is even now handled commercially at 2000 pounds per square inch and at 1000° F. Hydrofluoric acid and its many salts, once laboratory curiosities, are now common industrial chemicals. Anyone familiar with this acid, or its salts can appreciate the

potential difficulties involved in their handling. They may be considered as some of the most corrosive of the chemical agents. Even the common cereal wheat has been recently accused of being a bad actor. A depleted barley supply encouraged wheat to be used as a mash for the distillation of alcohol and certain alcoholic beverages; and it is this wheat mash that was so corrosive that it even threatened the future of Scotch and soda.

#### **Factors Involved in Corrosion Costs**

There have been many references to the world costs of corrosion, but to understand thoroughly what corrosion costs us, it seems only reasonable to discuss the various factors that contribute to this cost. These factors may be tabulated as follows:

1. Costs of equipment, or plant replacement.
2. Loss of time, or upset production schedules caused by shut downs.
3. Cost of inspections and maintenance.
4. Cost of protective means other than maintenance.
5. Loss of product or conveyed material.
6. Costs of additional power to maintain flow of gas, fluid, or heat.
7. Contamination or discoloration of product, with associated loss in value.
8. Loss of artistic value, or eye appeal.
9. Cost of research.

With profit margins hovering near that thin red line, it is essential for the sake of the stockholders and

one's job that all these factors be thoroughly studied and understood. Here is where the certified public accountant and the engineer must collaborate and check notes in order to evaluate the many economic vagaries involved.

In the past it has been customary to evaluate the losses due to corrosion in the terms of metal equipment lost. Corrosion has properly been charged with more monetary damage than fire and flood together. Thus, it has been estimated that as high as 40 percent of all the iron and steel made is for the purposes of replacements occasioned by corrosion. When such a percentage is translated into dollars, it means expenditures of hundreds of millions of dollars. Such figures are indeed large even in these times!

#### **Equipment and Plant Replacement**

When the equipment fabricated from iron or steel is replaced due to corrosion the costs are intensified. One could cite any number of illustrations in almost any industry where corrosion has necessitated replacement of expensive equipment in relatively short periods of time. The replacement losses in some of the chemical manufacturing industries is staggering. There are many instances where perfectly good pipe has been installed in soil only to corrode before any use could be made of it. One of the most disturbing problems of the Army Service Forces during the war was the high loss of metallic equipment caused by corrosion during overseas shipment. This loss was apparent in ordnance materiel as well as quartermaster canned goods.

A shut-down or slowdown caused by equipment destruction or replace-

ment is in many respects just as severe to management and the general public as is a shut-down or slow-down by strikes. In the former, wages carry on and the public is rarely so tolerant and understanding about plant inefficiencies as by strike. During the four war years, particularly, plants were just not supposed to have slowdowns because of the "accidents" of corrosion. In those years, a slowdown or shut-down was also in danger of being prolonged because of the difficulties in forcing the many barriers of priorities. And today, shortages of material are having a similar effect. In short, a plant certainly loses considerable by any such interruption in its normal production rate.

#### Maintenance Costs

With labor costs closing up the profit lines, the factors of maintenance, re-installation, and inspection become more important factors than henceforth estimated. The traditional methods of painting require in themselves considerable labor. Recent estimates indicate that labor's share of maintenance costs is around 75 percent. This figure may soon be exceeded if better means of avoiding corrosion are not developed.

Few reliable figures are available on the maintenance costs in the periodic painting of ocean-going ships, but it is known that the average ocean-going ship must be repainted every 22 weeks. It is also known that outside iron and steel structures on the inland should be painted at least twice yearly. All such maintenance requires millions of gallons of paint and considerable high-priced labor. The paint industry, which de-

rives a large percentage of its being from corrosion, is a multi-million-dollar industry.

There are many means of reducing corrosion other than by routine maintenance. These means are by water treatment, phosphatizing, counter electrolytic methods, application of plastics, etc. While such methods reduce the ravage of corrosion with considerable savings, they do not come free, and they also require maintenance.

#### Loss of Products

It is almost impossible to estimate the losses in dollars incurred by the losses of product or conveyed through leaks caused by corrosion. The average pipeline or water superintendent rarely knows of these losses until the leaks themselves are acutely manifest, or until a material balance shows a definite leakage. When one considers the many millions of miles of water, gas, oil, and other pipelines of different sizes in different places, it is not inconceivable that a definite percentage of these lines are losing products at different rates at this very moment.

Power and heat, and the conveyance of these forms of energy cost money. All lines, be they four feet, four inches, or one-fourth inch in diameter, become corroded over a period of time and acquire layers of corrosion products, or become pitted, presenting conditions which resist the flow of fluid, gas, or heat. It is well known that many iron pipes may last 50 or 100 years without rupture, but it is not so well known that the flow of fluid, gas, or heat through these same lines becomes retarded the day after installation. This varies considerable with vari-

ous lines, but it is evident enough. Such pipe may not show any rupture, but will show a high percentage depreciation in carrying power in a few years. The flow of heat through pipes and tubes is a function of the over-all coefficient, and this coefficient, in turn, is largely dependent upon the film coefficients. The moment a smooth, clean pipe becomes tarnished, corroded, or covered with products of corrosion, these film coefficients react to resist the flow of heat. It is not unusual for the over-all coefficient to be lowered 50 percent over a short period of time in some evaporators, or boilers. This country has always had an abundance of economical power, and the loss of a few million BTU's here and there certainly has not disturbed our national complacency. Is it smart to disregard these power losses due to corrosion? Some rapid calculations will convince the skeptical that these losses also run into enormous sums of money.

#### Power Losses

The navies of the world have been extremely concerned with hull corrosion as it effects friction. Anyone familiar with water friction realizes the vital part this friction plays at the higher speeds, where power consumption reaches diminishing returns. The high-speed aircraft carriers, battleships, cruisers, and destroyers take advantage of every artifice to gain one more knot of speed. Recently published data of the British navy revealed that such craft lost from one to two knots speed after a six-month cruise in temperate waters, or it was found necessary to expend 50 percent more horsepower to maintain a speed of

20 knots. How vital this factor was can be revealed when Britain needed certain munitions and materials on such short notice during the Battle of Britain: vital and much-needed payloads of oil had to be reduced by necessity of speed, the speed of a destroyer often meant the saving of a precious convoy, key naval engagements were won or lost by virtue of this added or lost knot—all because of frictional resistance, caused largely by the pitting type of corrosion. During the war, a ship could rarely take time out for dry docking and repainting.

#### Contamination and Discoloration

Contamination and discoloration may influence a product to the extent of making it undesirable for use. Such contamination may induce the undesired catalytic effects in chemical manufacture, off-flavors, and colors in food manufacture and processing, or simply a "strange" color to water which may be objectionable only from an esthetic point of view. Almost every person is familiar with "red water," and the questions aroused by the presence of red water from various water supplies. It may be of interest to refer to phosphoric acid manufacture at this point. This acid has among its many uses that of a foodstuff for some baking powders and soft drinks. In the manufacture of this acid for these products, certain high-chromium irons serve admirably but owing to a very slight solution and the subsequent contamination with chromium, the material will not pass the pure food and drug commission. Because of this, less-resistant cast iron or steel is used, whose contaminating iron is not forbidden by those laws. The high rate of corrosion of iron by

phosphoric acid is severe and the equipment turnover in these plants is quite large.

Corrosion often makes itself apparent by the evidence of red, green, or black rust as corrosion products. In the home, the bane of every housewife is red rust, spots on linens, rust on indoor and outdoor fixtures, darkening of aluminum kitchen ware, and last but not least, silver tarnish. Insignificant as these types of corrosion are from the point of a national dollar loss, they probably cause more mental anguish and comment than all of the more important cases of corrosion. One could safely say that no day at home passes without some mention to the above subjects.

Corrosion is rarely accused of being responsible for the loss of life or accidents as are fire and flood, but it is true that numerous accidents, and many of them fatal, are the results of corrosion. Boiler and refinery explosion accidents are not uncommon, unfortunately. Food spoilage in cans which have been corroded has caused illness of variable intensity. (Zinc in waters.)

### Corrosion Research

One cannot discuss the economics of corrosion without alluding to the costs and advantages of research. It is only in the past thirty years that effective means have been developed to combat corrosion. The past five years have seen more time and money spent on corrosion research than all the previous years put together. Now, why this belated and sudden emphasis on corrosion? There are several reasons. First, the greater demands of industry on the available materials have demon-

strated the inadequacy of these ordinary materials. Second, the high rate of acceleration of all industry during the war taxed materials to the limit. Many plants exceeded their rated output by two or three times or more. Such acceleration aggravated and intensified corrosion problems. Just because a plant doubles or triples its capacity does not necessarily mean that the corrosion rate would be merely doubled or tripled; the corrosion rate always presents more unfavorable ratios. Finally, the spirit of competition, high labor costs, scarcities and cost of material caused many an operation to be confronted with that red line. Much evidence indicates that in the future, mills of profit must be captured where cents had previously been the profit margin. The rather sudden or delayed realization that corrosion costs involve more than equipment alone has invited some hasty revisions in the programs of the research laboratories of the nation.

One paper mill out of every five has gone to alloy steels, and it can be demonstrated that maintenance in those mills has been reduced from 20 to 30 cents per ton of pulp on the 1937 basis. An expenditure of \$8,000 and some volunteer time over a period of two years on the problems of ice-can corrosion in the refrigeration industry enabled the life of those cans to be doubled and resulted in a saving of about \$1,000,000 a year. Those are just two cases of the enormous savings that can be entailed by the application of corrosion research and corrosion prevention. There are many means available for saving money in the plant,

the pipeline, or in the home by use of corrosion prevention or mitigation equipment, devices or material. One needs but go to any technical or engineering magazine to see that the frequency of corrosion papers and corrosion advertisements have increased fivefold in the past twenty years. Many colleges, universities and technical schools now offer courses in corrosion and chemical properties of materials of construction. Junior engineers can now be trained in these subjects to a greater extent than has been anticipated. This can be done by most of the educational institutions.

It is interesting to note that, in the past few years, every major technical and engineering society has appointed a committee or sub-com-

mittee of corrosion. The organization of the National Association of Corrosion Engineers was late, but certainly welcome. The war demands for secrecy and security made the exchange of corrosion information most difficult. It is time now for this pent-up information to be loosed. This association should continue to take and intensify its vigorous steps to promote corrosion research, corrosion information, and corrosion study in every phase of industry and life.

Editor's Note: The foregoing is an extract of the speech presented by Mr. Rohrman during the General Assembly of the National Association of Corrosion Engineers 1946 Conference and Exhibition, held in Kansas City.





## Use of Sodium Chromate as a Corrosion Control Medium in Gas Condensate Wells

By

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CAUSES of corrosion in gas-condensate wells are not well understood, and in helping the natural gas industry with this problem, the Bureau of Mines has tried to find an immediate means of controlling the corrosion rather than to use its personnel in fundamental research on the nature of the metal losses that can weaken equipment to the point of failure in six months of exposure. Two principal approaches to the problem are being made: (1) a search for an inhibitor, or treating agent, that will prevent the corrosion of gas-condensate well equipment; and (2) the testing of alloys that will resist the corrosive effects of the fluids from wells now affected. This report deals primarily with inhibitors, and particularly with the use of sodium chromate.

Before tests were made in the field to determine the usefulness of sodium chromate as an inhibitor, it was tried in the laboratory in separate corrosive solutions of carbon dioxide, five fatty acids, and phenol. All of these materials may be present in corrosive gas-condensate fluids. In

each test, the use of 1,000 parts per million of sodium chromate in the corrosive solutions reduced rates of corrosion 95 percent, on the basis of test exposures simulating conditions in flowing wells.

Tests lasting approximately 60 days were made in an East Texas field on a gas-condensate well subject to severe corrosion, to determine whether a solution of sodium chromate injected into the lower end of the tubing through the annular space would act as an inhibitor of the corrosion in progress. When the solution was injected at such rate that two to three pounds of sodium chromate in solution flowed to the surface with each million cubic feet of gas produced, the iron content of the effluent water was reduced from 70 to less than 2 parts per million, and the rates of corrosion measured with coupons exposed in the tubinghead were reduced from 0.045 to 0.004 inch per year uniform penetration.

Tests begun in a Northwest Louisiana field in October, 1945, have indicated that iron in the water flowing from the tubing may be reduced from 100 to 4 parts per million, and rates of corrosion of coupons exposed in the wellhead may

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\*Now associated with Phillips Petroleum Co., Bartlesville, Okla.

be lowered from 0.045 to 0.004 inch per year uniform penetration when 1.6 pounds of sodium chromate are used with each million cubic feet of gas flowing from the formation.

Corrosion seemed to have been reduced materially in the wells on which the tests with sodium chromate were made, although it was not practicable to verify such conclusion by inspection of the well fittings before and after the tests. It has been found that part of the sodium chromate used in the wells is converted to acid-soluble, reduced-chromium compounds, principally chromic hydroxide, which, with sodium chromate, will collect on the walls of the tubing when not enough water is injected. It is believed that the gas from reservoirs on which pressure has declined 1,000 pounds per square inch or more may be under-saturated with respect to water, because the injected solutions apparently are evaporated when injection rates are six gallons of water or less per million cubic feet of gas produced, and a deposit of sodium chromate collects inside the tubing near the formation. The rate at which the deposit collects varies inversely with the rate of solution injection. The deposit does not obstruct the flow of fluid at the sand face, however, and can readily be washed out of the tubing with water injected at the casinghead.

Gas-condensate wells in which the annular space between the tubing

and casing is closed with a packer or a mud filling are difficult to treat with solutions of inhibitors. To overcome the difficulty of introducing a liquid or a gas into the lower end of the tubing of such wells, a wellhead magazine was devised for dropping sticks of solid sodium chromate into the tubing against the flow of fluid under high pressure. A test of this method of introducing a treating agent into wells showed that sticks of sodium chromate would fall the length of a 2½-inch tubing in less than 30 seconds against the upward movement of fluid flowing at the rate of three million cubic feet per day. The sticks, prepared for the preliminary test to dissolve rapidly, provided corrosion protection lasting approximately three hours.

Laboratory and field tests have shown sodium chromate to be a promising inhibitor of corrosion in gas-condensate wells. The injection of aqueous solutions of sodium chromate into wells seems practicable if the space between the casing and tubing is open. When a solution of a solid inhibitor is used in fields where reservoir pressure has declined, enough water should be injected to saturate the gas from the formation, and prevent the precipitation of a deposit in the tubing. Tests in progress indicate that wells in which the annular space is closed may be treated by dropping sticks of solid sodium chromate into the tubing against the flow of the fluid.

# Construction and Ratings of Copper-Oxide Rectifiers for Cathodic Protection of Pipelines

By L. W. Burton and C. E. Hamann

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**C**OPPER-OXIDE RECTIFIERS have been used extensively in a wide variety of applications where d-c power is required. One of the applications in which these rectifiers have found wide acceptance is cathodic protection of pipelines or similar equipment. The copper-oxide rectifier is particularly well adapted for this type of application, due to its inherent reliability and long-life characteristics.

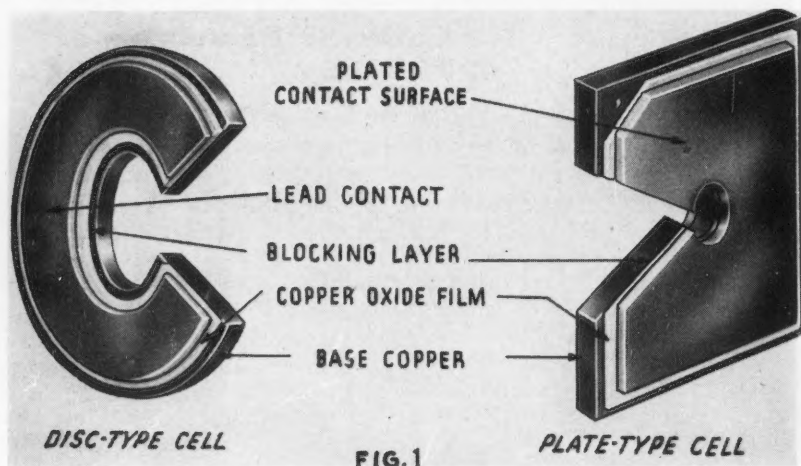
Most rectifiers used for cathodic protection are installed outdoors in locations where the summer temperature may range as high as 100 to 120° F., and winter temperatures considerably below zero. Cathodic applications of this type, however, are quite similar to those of standard industrial applications on which complete data are available. In fact, considerable field experience has been gained during the past 10 years or more in the use of copper-oxide rectifiers for this particular type of application, commonly called "cathodic protection," as well as for similar applications for the prevention of electrolysis drainage into pipelines or similar equipment.

This discussion will be divided into two general parts: the first will be a technical discussion of the operating and application characteristics of the copper-oxide cell. The second discussion will include the specific use of copper-oxide rectifiers

for the prevention of corrosion on pipelines and similar installations.

Early in 1920, while the photoelectric properties of cuprous oxide were being studied, it was found that under certain conditions the resistance of this material was greater to the flow of current in one direction than in the other. Since this valve action was found to supply the necessary characteristics of a rectifier, work was started to develop a manufacturing procedure. About 1928, the copper-oxide rectifier was introduced for industrial applications. It has been successfully and widely used ever since, for applications ranging from extremely small units, rated in micro-watts or milliwatts, to large installations running into many hundreds of kilowatts.

The manufacturing process of this copper-oxide rectifier has remained essentially the same, but developments and improvements have been incorporated from time to time. Special selected Chilean copper, which is used, undergoes many tests before it is approved for the processing required to form copper-oxide rectifier cells. A thin film of cuprous oxide with an outer layer of cupric oxide is produced by heating the copper disc or plate to a high temperature and quenching it in water. The cupric oxide is then removed, leaving the cell with a layer of cu-



prous (red) oxide on the base copper.

The junction between the base copper and the red oxide has the valuable property of permitting current to flow easily from oxide to copper, but offers a high resistance to the flow of current from copper to oxide. When these cells are assembled into a rectifier circuit, the positive terminal will be the one that is connected to the copper, and the negative terminal will be that which is connected to the oxide surface.

Contact with the oxide surface can be made in either of two ways: One method is to use a lead disc, or washer, which is held against the oxide surface at a definite pressure. The other method is to electrolytically deposit, or plate, a coating of a metallic conductor, such as nickel on the oxide surface. This plated film is then used as an accumulator of the electric current over the entire oxide surface. A  $1\frac{1}{2}$ -inch disc-type cell, as well as the  $4\frac{3}{8}$ -inch by 5-inch

plate-type cell is illustrated in Figure 1. The plate-type cell can be constructed with the oxide surface on one or both sides.

#### Construction of the Copper-Oxide Stack

Each copper-oxide cell has a definite rating, both in volts and in amperes, depending upon the construction, or grouping, and the circuit. It is customary to arrange these cells in series and parallel, or series-parallel groupings, in order to increase the output rating to the desired value. The cells are arranged on an insulated bolt, and the assembly is usually referred to as a copper-oxide rectifier stack. The stack, with disc-type cells, consists of an assembly of  $1\frac{1}{2}$ -inch diameter cells with contact made to the oxide surface by means of a lead disc. The whole assembly is held at a uniform contact pressure by means of a tempered spring washer on the end of the assembly. In order to dissipate heat and increase the rating of a group

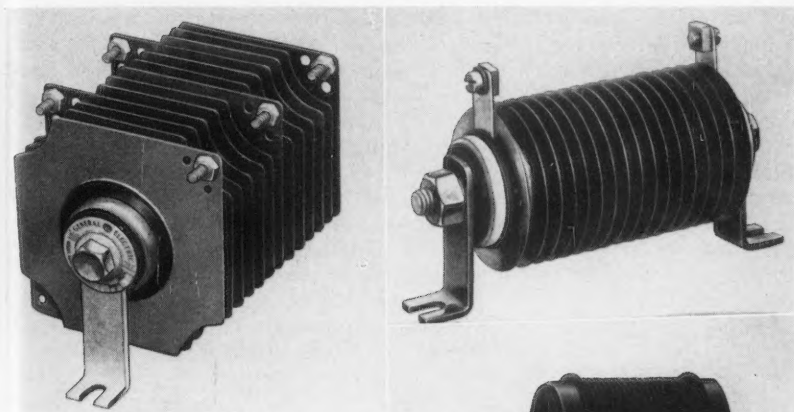


Figure 2—Illustrates method of dissipating heat in air-cooled stacks by use of radiating fins, and spacers between cells.

of cells, it is customary to use radiating fins as well as spacers between cells. (Figure 2.)

The construction of the stack using the plate-type cell is similar, with the cells separated by sufficient space to allow cooling either with forced ventilation or natural circulation of air. (Figure 3.)

The identification of the terminals on a copper-oxide stack depends upon the circuit into which the rectifier is to operate. For example, an assembly with five terminals represents a full-wave stack with the two outside terminals tied together for a positive; the center terminal negative, and the remaining two intermediate terminals are for the a-c power supply. A stack in which all of the cells are arranged in the same direction is a half-wave stack, and can have either two or three terminals. In this case, it may be used in a half-wave circuit or in a full-wave

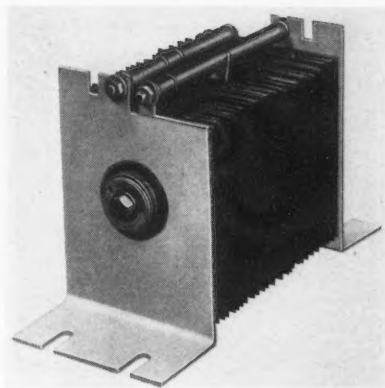


Figure 3—Stack using plate-type cell so constructed as to permit cooling by either forced draft, or natural air circulation.

circuit where two, four, or more assemblies are required.

A copper-oxide rectifier is considered to be electronic in operation.

Because of this characteristic and, as long as the rectifier is operated within its specified rating, its life is considered unlimited. The rectifier does not deteriorate when not in operation, and no forming period is required even when it has been out of the circuit and out of operation for years. This means that it is always ready to function with normal characteristics as soon as power is applied.

### Characteristics of the Cell

The characteristics of the copper-oxide cell are illustrated in Figure 4. This rather complicated group of curves shows the voltage drop in the conducting direction for various current values and temperatures. Also, the value of the leakage current is given for various voltages during the blocking portion of the operating cycle. However, in using copper-

oxide rectifiers, it is not necessary to resort to a curve of this type, since all of this information is assembled in a simple tabulation.

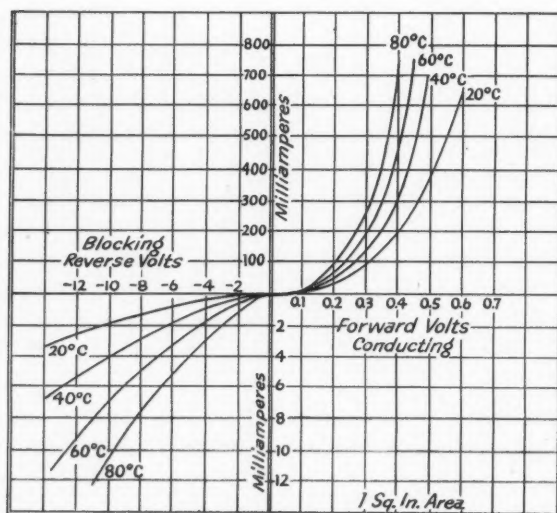
There is some data of general information that can be obtained from this group of curves, including the fact that the rectifier has an inverse temperature coefficient. This means that the resistance decreases as the temperature increases, partially offsetting the positive characteristic of copper in the transformer, in which resistance increases with temperature.

From the curve, it will be seen that the value of the leakage current, when the cell is blocking, is very small—less than five milliamperes per square inch under normal conditions. It will also be noticed that this leakage current increases with temperature. This increase in leakage current with an increase in

temperature is one reason for operating copper-oxide rectifiers with the minimum of temperature rise.

### Temperature Characteristics

In a copper-oxide rectifier, heat is generated due to the resistance to the flow of current in the conducting direction, and to the leakage current in the blocking half cycle of operation. With normal operating conditions, the temperature



DC Voltage Current Characteristics  
Copper Oxide Rectifier Cell

Fig. 4



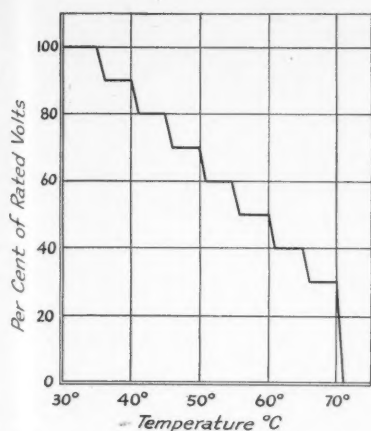


Fig. 5 Output Rating Above 35°C

rise of a cell is from 10° to 15° C. above ambient, or room temperature. With fan cooling, this temperature rise is usually from 3° to 5° C.

The rectifier is designed to operate at full-rated output up to 35° C. (95° F.). Above this value, it is necessary to derate the voltage to a value less than normal, according to the tabulation shown in Figure 5. For example, a rectifier group designed to operate at normal output at 35° C., would be derated 30 percent in voltage to a value of 70 percent of its normally rated voltage output when operating at 50° C. Under these conditions, there is no derating in the current output.

### Rectifier Location

In designing equipment in which copper-oxide rectifier stacks are used, it is desirable to locate the stacks in the coolest portion of the enclosure. In other words, they should be located where the operating temperature will be as low as possible. This is usually in the lower portion of the enclosure where heat from other equipment, such as transformers and resistors, will not flow past the rectifier units. In a long, narrow casing, there is usually some chimney effect, due to the heat generated by the transformers and other equipment, which tends to cause a natural flow of air over the rectifier elements for cooling.

In applications where the power output is above 300 to 400 watts, it is customary to use forced ventila-

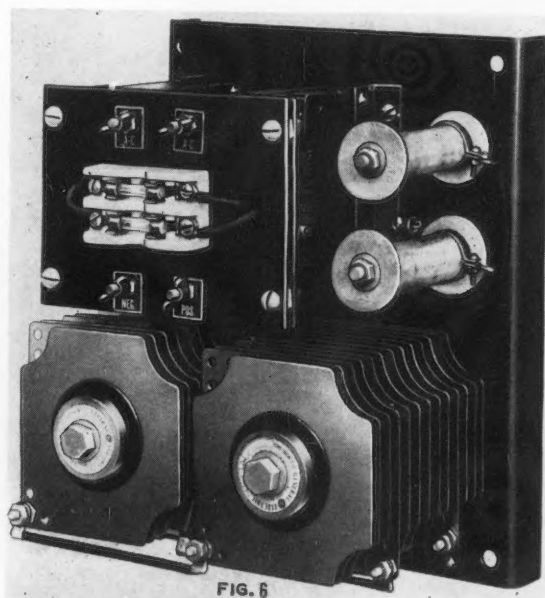


FIG. 6

Figure 6—Typical design of small air-cooled unit.

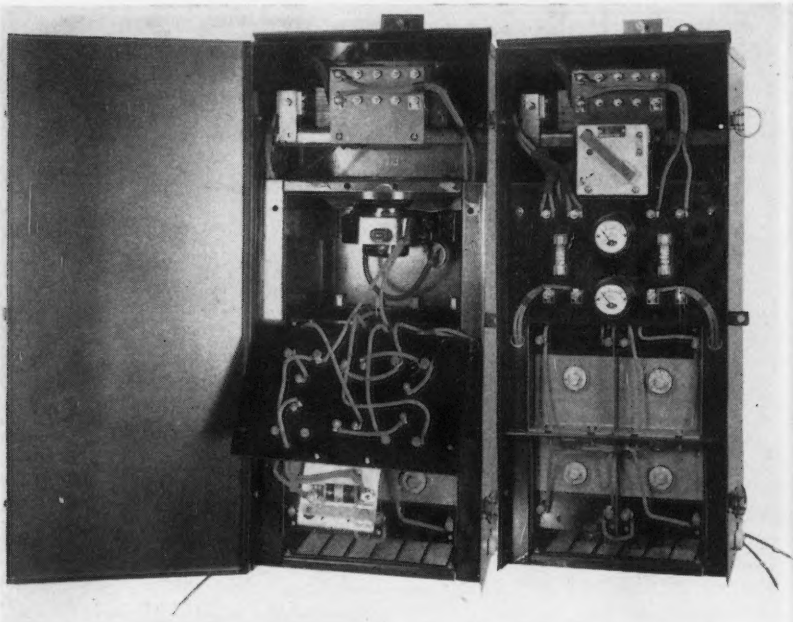


Figure 7—(Above) Two views of a G-E fan-cooled rectifier for cathodic protection of pipelines showing (left) terminal board dropped revealing fan location, and (right) with terminal board in place and baffle plate removed to show location of copper-oxide units.



Figure 8—(Right) Interior of same unit as in Figure 7, but with all components in place.

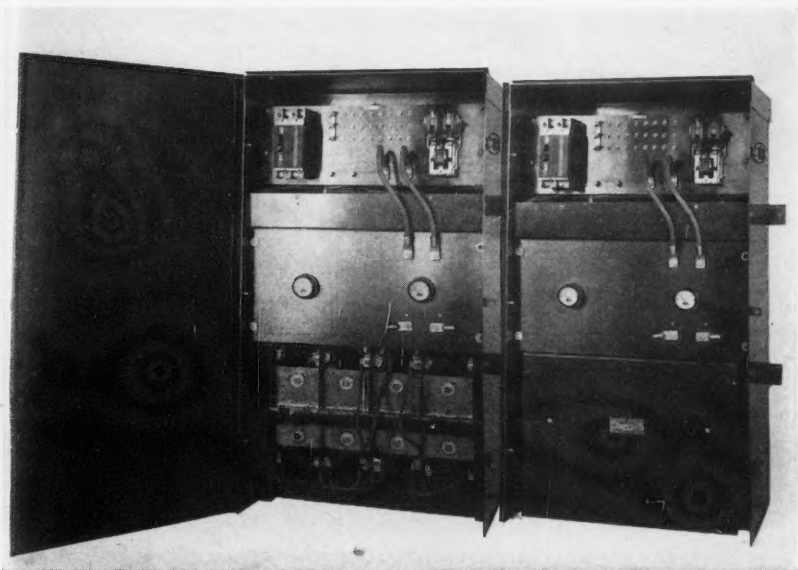


Figure 9—Two views of a G-E rectifier rated at 1,600 watts, showing (left) door open and baffle plate removed to reveal copper-oxide units, and (right) with baffle plate in place.

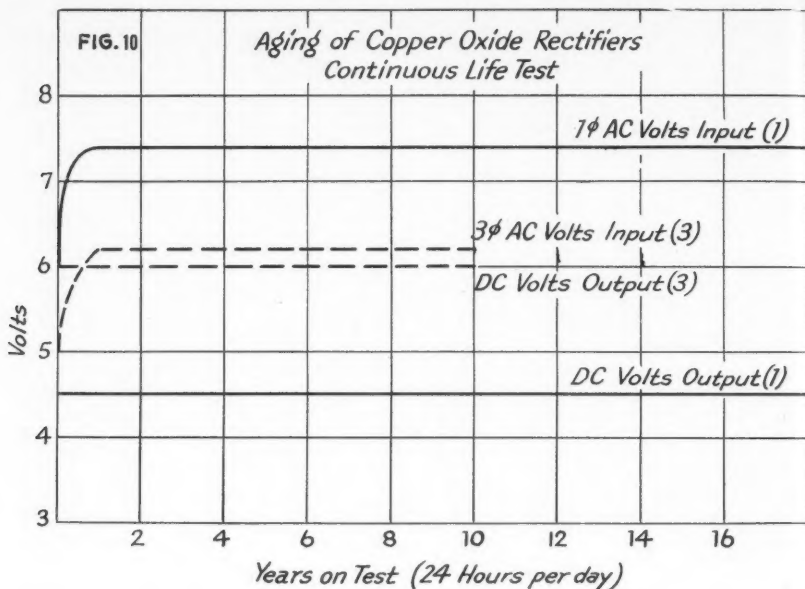
tion. This is usually provided by a low pressure ventilating fan, which will provide free flow of air past the rectifier stack section. The ventilation should be so designed that there is an equal distribution of air over the entire stack area. The capacity of the fan will depend on the rectifier rating. For example, in a rectifier rated at an output of 3-kw, the fan is usually designed to deliver from 600 to 700 cubic feet of air per minute. This output is based on using the plate-type cell, which is employed on applications using forced ventilation where high-current outputs are required.

Typical rectifier designs are given in illustrations which follow. Figure

6 is a small unit for normal cooling, and Figures 7 and 8 show views of a fan-cooled unit, illustrating the location of the fan, stacks, and transformer. Figure 9 shows two views of a larger unit, rated at 1,600 watts. The copper-oxide stacks are located in the lower section of the rectifier, where cool air and good ventilation are available.

#### Aging

Another copper-oxide rectifier characteristic to be considered in the design of transformers used with rectifiers is "Aging." Aging, which develops with time, is indicated by an increase in the resistance of the rectifier. This change in rectifier resistance, reflected in the output of

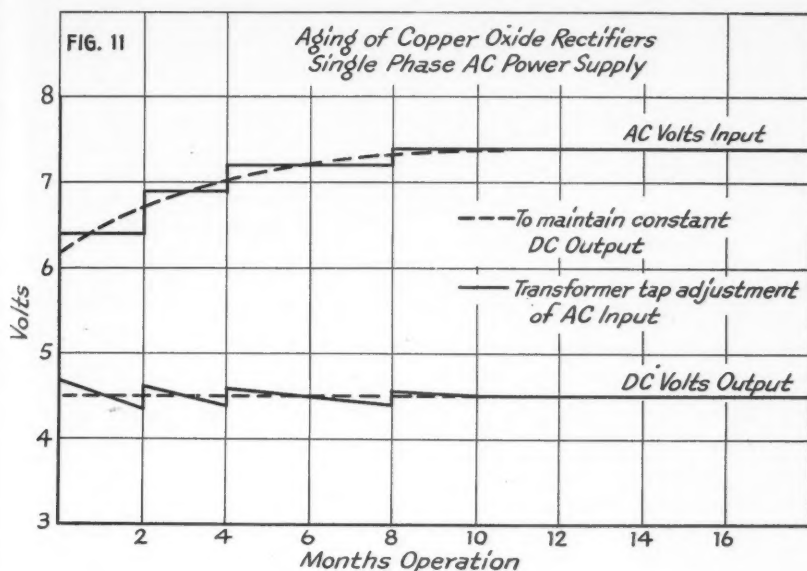


the unit, is illustrated in Figure 10. This aging condition will show up as a slight decrease in output voltage with a constant a-c voltage supply. To overcome this decrease in d-c output voltage, and to maintain it at a constant value, it is necessary to increase the a-c input voltage proportionate to the amount of aging. Aging or readjustment of the rectifier output is usually completed within six months to a year of service, after which time the d-c output will remain constant with a constant a-c supply voltage. The published rating of rectifier stacks is on the basis of the aged condition.

In actual practice, it is not convenient, nor economical to slowly vary the a-c voltage over a length of time. It is much more convenient to arrange taps on the transformer in order that the transformer voltage can be increased from time to

time during this initial aging period. These taps will essentially hold the d-c value constant, as illustrated by the dark lines in Figure 11. The dotted lines show the average value which is necessary to maintain constant d-c voltage output. After this initial readjustment has been completed, no additional changes are necessary because the output has been stabilized. This stabilization of the output, together with the fact that the d-c voltage remains constant after this initial aging period is the reason for the long dependable life of the copper-oxide rectifier. As far as it is known, the life of the rectifier will continue indefinitely so long as it is operated within its rating and under the conditions recommended.

The copper-oxide rectifier stack is efficient. Its efficiency will vary, depending on the type of circuit, the



rating, and the operating conditions. In a single-phase full-wave circuit connected to a resistance load, the rectifier stack efficiency at rated output will be from 60 to 65 percent. In three-phase operation, 85 percent efficiency is obtained at full-rated output. At low temperature, the efficiency will be slightly less but, at higher operating temperatures, the efficiency will be increased slightly due to the lowering of the internal resistance of the rectifier.

#### Power Factor

The copper-oxide rectifier is a resistance device, and as such operates at approximately unity power factor. When used in a circuit with a transformer and connected to a normal load, such as a resistance device, the power factor is usually 95 percent or better.

Before taking up the ratings of rectifier cells or groups of cells, it is necessary to study the circuits in which rectifiers are generally used. There are three single-phase circuits and one three-phase circuit, which include the majority of applications in which metallic rectifiers are incorporated.

The simplest type of rectifier circuit-consists of an a-c power supply, with a rectifier connected in series with the load, as shown in Figure 12. This type of circuit provides an intermittent pulsating power supply, with the conducting period equal to one-half of the cycle. The actual calculations of the a-c and d-c voltage will depend on the particular rectifier characteristics. The theoretical values of a perfect rectifier will give  $E_{dc}$  equal to  $0.45 E_{ac}$ . However, in actual use, it will be found that with

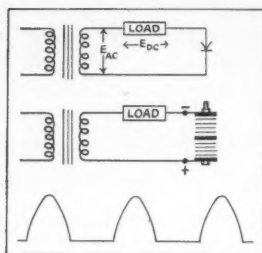


Figure 12  
Half Wave Rectifier

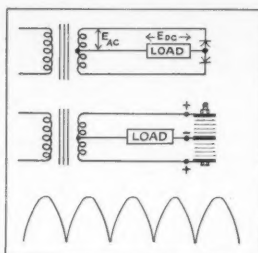


Figure 13  
Full Wave, Mid-Tap

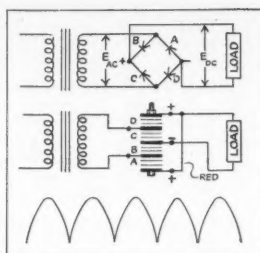


Figure 14  
Full Wave, Bridge

an a-c voltage of 6 volts, the d-c output will be about 2.2 volts or practically  $E_{dc} = 0.36 E_{ac}$ . This same proportion of output will hold for practically any combination of cells at various voltage values. Another characteristic of this circuit is that the heating value of the current is higher than that measured by the d-c ammeter. If the d-c ammeter reads 1.0-ampere, the heating current will be about 1.57 amperes, and the transformer and other parts will have to be designed to this value. This circuit is normally used for low voltage power output.

The full-wave circuit, which requires a mid-tap transformer as illustrated in Figure 13, is another circuit which is often used for low-voltage outputs. The output is full-wave, with the voltage reaching zero twice each cycle. In this circuit, the theoretical d-c voltage  $E_{dc}$  is equal to  $0.9 E_{ac}$ , which is the a-c voltage measured across one-half of the transformer, or to the mid-tap. In other words, if a transformer is used similar to that referred to in the above application, with an over-all voltage of 6 volts and a mid-tap at 3 volts, the d-c output voltage will be 2.2 volts. The current, however, will have twice the rating of the half-

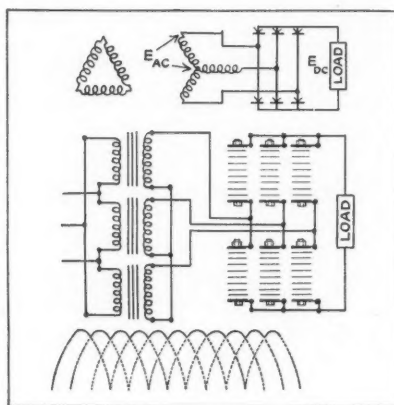


Figure 15  
Three-Phase, Full Wave, Bridge

wave circuit already described, since two cells, or two legs of the circuit are used. In this circuit the d-c ammeter will read essentially the correct heating value of the circuit, because an a-c ammeter inserted in the circuit would read only 1.1 times higher than the d-c value. This represents a slightly more efficient circuit, as far as the transformer is concerned, than that of the half-wave circuit.

The single-phase circuit, which is used in practically all metallic rectifier applications, is the one referred



to as the full-wave bridge-type circuit, illustrated in Figure 14. In this circuit there are four legs to the grouping of the rectifier cell. This circuit will give the same wave shape as that shown in Figure 12, but has the advantage in that a mid-tap transformer is not required. In this circuit, the a-c power will flow for one-half cycle through one leg (B) of the bridge, then through the load and back to the other leg (D) to the other side of the a-c power supply. During the other half cycle, the other two legs of the bridge circuit (A) and (C) will be conducting power. The value of the d-c voltage rating of the load  $E_{dc}$  is equal to  $0.9 E_{ac}$  for a theoretically perfect rectifier. However, in actual practice, by referring back to the same type of transformer with an output of 6 volts, the d-c output would be 4.4 volts, with twice the current rating of the half-wave unit,

or the same current rating as the full-wave mid-tap rectifier, but with twice the voltage output of this unit. And here again, the same ratio of output, d-c voltage to a-c input voltage, would apply to any voltage range as far as practical service is required.

It is customary to use a three-phase power supply where higher outputs are required, and efficiency of operation is important. There are several three-phase circuits which are used, but the most common is the one illustrated in Figure 15. This circuit, usually referred to as the three-phase, full-wave bridge circuit, has six legs, or branches arranged in groups, with each group supplied from one of the three transformer secondaries. The theoretical d-c output voltage  $E_{dc}$  is equal to  $2.34 E_{ac}$ . In a practical application, however, using copper-oxide rectifiers, the d-c output of 6 volts could be obtained

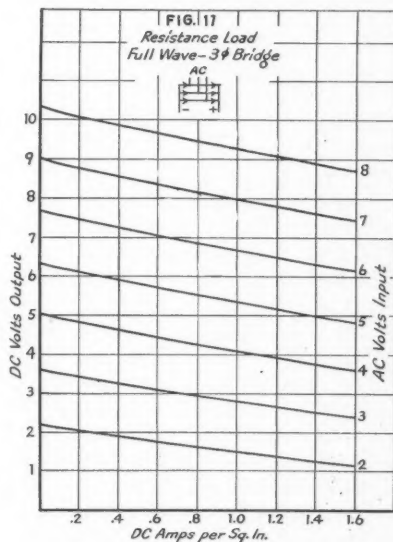
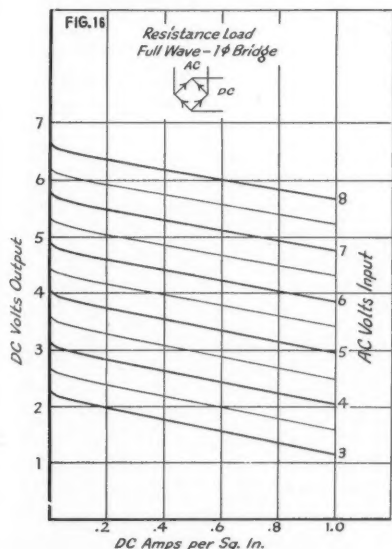


TABLE NO. 1  
Copper-Oxide Rectifier Stacks

	Cell		Cooling	D-C Volts	Amperes	A-C Volts	
	Dimension	Area Sq. In.				Normal	Maximum
Single-phase half-wave—Combination 1-1-1.	1 1/2" x 1 1/2"	1.1	N	2.25	0.25	6.2	8.2
	3 3/8" x 4 3/8"	13	N	1.8	2.0	4.9	6.3
	3 3/8" x 4 3/8"	13	F	2.25	2.2	6.2	8.2
	4 3/8" x 5"	38	N	1.8	3.0	4.9	6.3
	4 3/8" x 5"	38	F	2.25	6.3	6.2	8.2
Single-phase full-wave mid-tap Combination 2-1-1.	1 1/2" x 1 1/2"	1.1	N	2.25	0.5	6.2	8.2
	3 3/8" x 4 3/8"	13	N	1.8	4.0	4.9	6.3
	3 3/8" x 4 3/8"	13	F	2.25	4.3	6.2	8.2
	4 3/8" x 5"	38	N	1.8	6.0	4.9	6.3
	4 3/8" x 5"	38	F	2.25	12.5	6.2	8.2
Single-phase full-wave Combination 4-1-1.	1 1/2" x 1 1/2"	1.1	N	4.5	0.5	6.2	8.2
	3 3/8" x 4 3/8"	13	N	3.5	4.0	4.9	6.3
	3 3/8" x 4 3/8"	13	F	4.5	4.3	6.2	8.2
	4 3/8" x 5"	38	N	3.6	6.0	4.9	6.3
	4 3/8" x 5"	38	F	4.5	12.5	6.2	8.2
Three-phase full-wave Combination 6-1-1.	1 1/2" x 1 1/2"	1.1	N	6.0	0.75	5.3	7.4
	3 3/8" x 4 3/8"	13	N	4.8	6.0	4.0	5.7
	3 3/8" x 4 3/8"	13	F	6.0	6.5	5.2	6.7
	4 3/8" x 5"	38	N	4.8	9.0	3.8	4.3
	4 3/8" x 5"	38	F	6.0	19.0	5.2	6.7

N—Normal Cooling.

F—Fan Cooling.

\* Requires 3 3/8" fins and 1/8" spacers between each two cells.

with an a-c input voltage of 5.2 volts on each of the three-phase transformer secondaries. Here again, this same ratio applies for practical purposes with any desired value of d-c output voltage or a-c input voltage.

More accurate design data are included in the curves, Figures 16 and 17. The resistance of a rectifier varies with current, which accounts for the slope of the curves. The d-c amperes output is plotted in terms of current density per square inch. The area of the various rectifier cells is supplied in Table No. 1. With these curves, the a-c voltage required for any particular d-c output can be determined easily.

For example, in a single-phase, full-wave circuit, a current rating of 1/2 ampere, 4.5 volts, using a 1 1/2-inch cell, would have a current density of 0.45 ampere per square inch. Referring these values to the curves in Figure 16; we find 0.45 ampere at

the bottom of the chart, and the value of 4.5 is selected on the left-hand vertical scale marked "DC Volts Output." The intersection of these two values on the parallel curves "AC Volts Input" will represent the required a-c voltage. This value is approximately 6.3 a-c volts.

If, however, this rectifier were operated at a current density of 0.2 instead of 0.45, it would be found that the a-c voltage would be approximately 5.9 volts, in order to maintain the d-c output of 4.5 volts. Similar computations would apply if the d-c output were 45 volts, in which case the a-c voltage would also be multiplied times ten, giving the value of 59 or 63 volts, depending on the above described conditions.

A nomenclature has been developed for the identification of the circuit and the arrangement of cells in the copper-oxide or metallic

rectifier circuit. This nomenclature, called the stack combination, is divided into three groups of figures.

The first numeral represents the type of circuit, and is identified by the number of legs in this circuit. The numeral 1 represents the single-phase half-wave circuit. Numeral 2 is the single-phase mid-tap, and numeral 4 is the full-wave bridge. The three-phase, full-wave bridge is identified by the numeral 6 representing the six legs in the three-phase circuit.

Now, if a simple assembly of rectifier cells is so arranged that there is only one cell in each of the legs of the circuit, a definite rating can be given to this grouping. For example, a single-phase, half-wave assembly would have only one cell; the mid-tap circuit would have two cells, one in each leg, and the bridge circuit would have four cells. With this arrangement of cells, there is given a definite voltage and current rating, depending on the capacity or size of the cells. This information is also tabulated in Table No. 1, and covers a group of cells, with one in each leg of the circuit. Only three sizes of cells are listed in this tabulation although many more are available; however, these are not normally used in applications such as those described in this paper. Ratings are also included for both normal and fan cooling.

For example, referring to the third tabulation in which four cells are rated for a bridge circuit, it can be seen that the cell of the 38-square-inch area has a normal d-c voltage rating of 3.6 volts and 6 amperes for the assembly of four cells, with normal cooling; or 4.5 volts at 12.5 amperes, if fan cooled. The normal a-c

voltage required to obtain this output is 4.9 volts with normal cooling, or 6.2 volts for fan cooling, due to the higher d-c voltage rating.

Under "aging," it was mentioned that the a-c voltage was increased to maintain the d-c voltage constant. The value of maximum a-c voltage given represents the maximum voltage under the most adverse aged condition. Practically, the normal aged condition would be represented by a value about mid-way between the normal and maximum values given. Transformers having taps within this range would be sufficient to maintain constant d-c voltage output, although in design it is customary to furnish sufficient adjustment to take care of variations in a-c supply voltage with the same group of transformer taps.

The tabulation includes an assembly of one cell in series in each leg of the rectifier circuit or grouping. This assembly is referred to as the fundamental rectifier circuit. In order to increase the output-voltage rating of a rectifier assembly, it is necessary to add cells in series in each leg of the circuit. For example, an output of 45-volts d-c may be desired, using a full-wave bridge circuit in which a single-series cell has a rating of 4.5 volts. This, then, would require 10 cells in series in each leg, or a total of 40 cells to give an output of 45 volts. The normal a-c voltage would be 6.2 times 10, or 62 volts, with a maximum transformer tap up to 82 volts.

In like manner, cells can be operated in parallel to increase the current output. Again, referring to the circuit just discussed and, with a cell rating of 0.5 ampere for the bridge assembly, it would be neces-

sary to use four groups in parallel to give 2.0 amperes output. A rectifier to deliver an output of 45 volts at 2.0 amperes would then require a group of 10 cells in series in each leg of the bridge, and four such groups in parallel, or a total of four times ten, times four, or 160 cells, or a combination of 4-10-4. This arrangement then is the normal method of circuit identification or combination of cells used. In this identification, the first figure mentioned represents the number of legs or branches of the circuit. The second figure represents the number of series cells, and the last number or figure represents the parallel groups. The product of all of the numbers gives the total number of cells used in the rectifier assembly.

The arrangement of the cells within the stack or stacks is left to the manufacturer, because mechanical and cooling problems are involved pertaining to the number of cells that can be assembled in a single stack. In the case just analyzed, obviously 160 cells could not be assembled in a single stack. These cells could be grouped in two ways. In the first grouping, a stack of 40 cells could be arranged as a full-wave assembly 4-10-1, rated 45 volts at 0.5 ampere d-c. Four such stacks connected in parallel would give the required rating of 45 volts at 2.0 amperes. Here, each stack would have five terminals, with the two outside terminals connected together for the positive, the center negative, and the remaining two for the a-c supply.

The second combination for grouping the 160 cells would be to arrange a grouping of ten cells in series, with four such groups in parallel,

assembled 1-10-4; in which case, one stack would be used in each leg of the bridge-type circuit. As can be seen, there are a number of combinations which can be used for grouping the required number of cells. However, the grouping is usually determined by the manufacturer on the basis of the ease of manufacturing and the requirements of the user.

When a combination has been chosen, the voltage is built up by adding cells in series, after the circuit has been determined. Current ratings are then selected, corresponding as nearly as possible to the values given for the circuit. The cell size, or combinations in parallel are then built up. It can be seen that the most economical rectifier design depends upon the choice of voltage and current values which permit operating the combination at the maximum d-c values and amperage given for the rating. For this reason it is desirable to specify the limits in both voltage and current. In other words, if the rectifier rating and the application can be worked out as a unit, taking advantage of the full capacity of the rectifier grouping, then the most economical and desirable combination can be obtained. The selection of a voltage is comparatively easy, due to the low-voltage rating per cell, which can be selected in steps of 3.6 to 4.5 volts for single-phase operation. The current selection is also facilitated, due to the large number of combinations of ratings available, both with normal and fan cooling.

Thus far, only copper-oxide rectifiers have been discussed. The selenium rectifier has characteristics similar to those of copper-oxide rec-

tifiers. Its application is quite similar, and it makes use of the same circuits. The voltage per cell, however, is somewhat higher for selenium, resulting in fewer cells for a given output. The selenium rectifier usually requires less space than the copper-oxide rectifier when it uses the normal circulation of air for cooling. For fan cooling, the space required may be nearly the same, depending on the particular rating. The cost per cell of selenium is somewhat more than that of copper-oxide, with the result that the over-all cost of a rectifier using normal cooling may be above the same for both types. The operating efficiency of both types is essentially the same, with the result that the ratio between output d-c volts and input a-c volts is similar.

A tabulation of the ratings for various sizes of selenium cells is given in Table No. 2. From this tabulation, it will be seen that the output voltage of a full-wave single-phase bridge is 12 volts, with an input of 15.5 volts a-c and a maximum value of 18 volts. These values are all for normal cooling. No data are given for fan-cooling, since selenium does

not lend itself to fan cooling quite as readily for this type of application as copper-oxide, particularly where high currents and low voltages are required.

### Copper-Oxide Versus Selenium

If cost and efficiency are comparable, the question naturally arises as to which type of rectifier should be recommended for a specific application. Each type has its advantages and disadvantages, which must be weighed before arriving at a definite recommendation.

If size and weight are important, as in portable or aircraft equipment, selenium has a definite advantage. For a given convection-cooled rating, selenium weighs approximately one-seventh of an equivalent of copper-oxide, and takes up approximately one-quarter of the space.

If stability of rectifying characteristics is important, then copper-oxide has much in its favor. The rectifying properties of copper-oxide are inherent, and require no artificial forming during manufacture. There is no time delay in operation for "reforming," regardless of the length of time copper-oxide rectifiers have been idle.

TABLE NO. 2  
Selenium Rectifier Stacks

Rectifier Circuit	Maximum Current Rating at 35° C. (Unit Rectifier Circuit)														D-c Volts
Diameter of Cell..... Code Letter..... Number Cells in Stack.....	1" F 1 to 8	1" F 9 to 24	1" F 25 to 40	1 1/4" A 1 to 16	1 1/4" A 17 to 24	1 1/4" A 25 to 40	2 1/8" C 1 to 8	2 1/8" C 9 to 24	2 1/8" C 25 to 36	4 3/8" *H 1 to 16	4 3/8" *H 17 to 36	4 3/8" J 1 to 8	4 3/8" J 9 to 16	4 3/8" J 17 to 24	
Single $\phi$ H.W.....	0.13	0.10	0.08	0.25	0.20	0.18	0.60	0.50	0.40	2.00	1.85	2.50	2.25	2.00	6
Single $\phi$ Center Tap.....	0.25	0.20	0.15	0.50	0.40	0.35	1.20	1.00	0.80	4.00	3.75	5.00	4.50	4.00	6
Single $\phi$ F. W. Bridge.....	0.25	0.20	0.15	0.50	0.40	0.35	1.20	1.00	0.80	4.00	3.75	5.00	4.50	4.00	12
3 $\phi$ H. W.....	0.34	0.27	0.20	0.68	0.54	0.47	1.60	1.35	1.10	5.40	5.00	6.75	6.10	5.40	8
3 $\phi$ F. W. Bridge.....	0.37	0.30	0.22	0.75	0.60	0.52	1.80	1.50	1.20	6.00	5.60	7.50	6.75	6.00	16
Normal A-c Volts.....	15.5			15.5			15.5			14		15.5			
Maximum A-c Volts.....	18			18			18			16.2		18			

The rectifying properties of selenium are inherently less stable than those of copper-oxide. In manufacture, the relatively slight rectifying properties of selenium are fortified by building up a "blocking layer" by means of an electrical forming process. In common with many electrolytic devices, unforming takes place when selenium cells remain idle. The longer they remain idle, the more they "unform," with the result that when placed in a circuit again, they are subject to excessive leakage current until they are again reformed. This reforming may take a fraction of a second to several minutes, depending on the length of the preceding idle period.

Excessive unforming, resulting from several months of idleness, may require the applied a-c voltage to be built up slowly to prevent damage to the cells. This procedure is usually inconvenient in devices where the transformer voltage is not adjustable.

In high-current applications where fan cooling can be effectively employed, copper-oxide has an advantage. The applied a-c voltage can be increased, to permit normal output voltages at several times normal current density, in order that efficiency is not impaired. Fan cooling can be employed with selenium, but a loss in efficiency results. The applied a-c voltage cannot be increased above normal rating, regardless of the amount of cooling; hence, higher than normal output currents result in an increased forward drop through the cells, and lower than normal output voltage, with consequent lower efficiency.

For momentary high-current applications, such as circuit breaker

operation, copper-oxide is particularly well adapted. For short-duty cycles, it will handle many times its normal continuous current rating and still maintain rated output voltage. The current is limited only by the thermal capacity of the rectifier and the frequency of the duty cycle.

Selenium, on the other hand, is limited to its normal a-c input rating, even for momentary duty cycles; its output voltage drops quickly as the current is increased above normal, even though the thermal capacity is not exceeded. At ten to twelve times normal current density, the output voltage drops to zero.

Operating temperatures of copper-oxide versus selenium are points on which considerable confusion exists. Because the normal operating temperature of selenium is considerably higher than that of copper-oxide, it has been erroneously assumed that selenium is better adapted for operation in high ambient temperatures.

Reference to any published data will quickly show that the normal ratings of both types of rectifiers are based on 35° C. maximum ambient, and that for higher ambients, derating is necessary. The misunderstanding as to adaptability of these two rectifiers is doubtless due to the fact that selenium has a considerably higher temperature rise than copper-oxide—30° to 40° C., compared with 10° to 15° C. for the latter; therefore, selenium operates at a much higher total temperature than copper-oxide, but not at a higher ambient temperature.

Aging in a metallic rectifier is considered as an increase in forward resistance of the cells, requiring an increase in input voltage to main-



tain constant output voltage, or a loss in output voltage if constant input voltage is maintained. Both copper-oxide and selenium are subject to aging. In copper-oxide, aging appears to be a function of time and operating temperature; hence, higher current produces relatively little aging if adequate cooling is employed. In selenium, aging appears to be a function of time and current density, with temperature a relatively unimportant factor, provided it does not exceed safe limits. Hence, aging of selenium is greatly accelerated by high-current densities, regardless of the effectiveness of the cooling system employed.

If the relative value of these two seem confusing, the following recommendations may be helpful in choosing the type rectifier for a particular application.

1. If the service is intermittent and of short duration, consider copper-oxide.
2. If space is limited and weight must be a minimum, generally recommend selenium for continuous operation.
3. If the voltage is low and current high, requiring forced cooling, recommend copper-oxide.
4. If the voltage is high and current low, suggest selenium.
5. In all cases, however, consider the ultimate cost for a given rating.
6. Where temperature extremes are encountered, it is usually necessary to consider the characteristics of both types in detail.
7. When used in d-c circuits, the selenium rectifier tends to be unstable.
8. With selenium, the a-c power

supply must be stable enough to apply full voltage to the stack for reforming.

#### Use of Copper-Oxide Rectifiers

The foregoing discussion has included the technical selection and use of copper-oxide elements. How these elements have been used in equipment for protection of pipelines will now be discussed.

The actual design and layout of the electrical system involves a number of problems, one of which includes the power supply. The problems are: will the power supply be obtained from a high line of approximately 2300 volts, and then stepped down, or will the power be bought locally and metered at each rectifier, or group of rectifiers? The answers to these problems will help to decide the spacing of the rectifiers, and their capacity. These answers will also help to decide whether a number of small capacity units closely spaced should be used, or whether a few large rectifiers, possibly over-protecting part of the pipeline, and spaced at greater distances, are to be used.

Let us consider a power supply from a 2300-volt line. One system would be to use an oil-cooled, step-down transformer to be connected directly to the rectifier stacks for the voltage of the proper value. This method is probably the most direct, and involves a minimum of equipment. This system would involve a high-voltage, oil-cooled step-down transformer with rectifiers mounted as another unit.

Although this system is probably the simplest method and involves the least equipment, it would include a special transformer which, because of the comparatively small

production, would be expensive to produce. It is also difficult to provide the necessary taps for adjusting the output of the transformer to compensate for aging and various output voltages required from the rectifier bank. Any change in transformer taps would involve climbing the pole, disconnecting the high voltage, and changing the taps in the oil of the high-voltage transformer. Also, it is not convenient to vary the voltage applied to the pipeline in different locations with varying soil conditions if a uniform step-down transformer of a particular secondary rating has been used as standard.

Another approach to this problem is one that has been used quite extensively, and that involves a standard step-down transformer of 2300-volts to 115-volts. A transformer of this type is in wide use, and is economical to produce, due to the quantities required for domestic power distribution. The rectifier is designed to operate from 115 volts, with a step-down transformer to deliver the proper voltage to the rectifier elements. This design allows the output to be adjusted by taps on the secondary or primary of the transformer. The rectifier, in this case, can be so mounted that adjustments can be easily made from the ground. The standard step-down to 115 volts also provides a source of power for operating the ventilating fan, if one is used.

The arrangement of a rectifier of this type is quite simple. The stacks are arranged in the bottom of the case, with the transformer above. In the case of natural ventilation, the louvers or openings are at the top, and are so protected that moisture

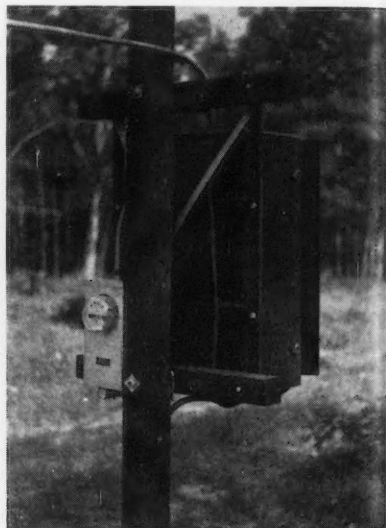
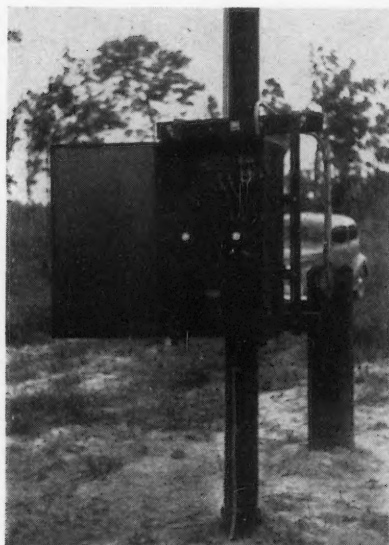
cannot be blown inside of the rectifier. With fan cooling, a novel arrangement of the casing is used, although any other arrangement is possible. With fan cooling construction, a double-walled casing can be used, to permit air to be taken up the inside, forced over the stacks and transformer, and then exhausted down between the double-wall construction, which includes all four sides. This arrangement has the advantage of keeping heat from pocketing, or from readily being radiated to the equipment when the sun is shining directly on the casing. It also forms a barrier around the intake portion to keep leaves, insects, and other material from accumulating on the intake screen. This last consideration is quite important, since an accumulation on the intake would limit air circulation. Other items that are usually included with the rectifier and large fan-cooled units include a voltmeter, ammeter, contactor, overload switch or fuses, wind switch to open the contactor in case of failure of the ventilating system, and any other items which may be required for best performance and ease of operation.

Some consideration should also be given to the finish of these rectifiers. A light-colored paint or aluminum paint would help to radiate the heat from the sun. However, since light color attracts more attention to the enclosure, it has been found advisable to paint the units a darker color, possibly green, to harmonize with the surroundings.

These units, particularly the larger ones, are factory assembled ready for installation. Some rectifiers have been shipped with the units knocked down, and later assembled on the



Figures 18-19-20—Three views of special designed, pole-mounted copper-oxide assemblies which have operated under adverse weather conditions for various lengths of time up to 12 years.



Figures 21-22—Front and rear views of a pole-mounted 1,640-watt rectifier of the fan-cooled type.

job. This involves a casing easily assembled from prefabricated parts, into which the transformer and stacks are assembled, usually eliminating excess parts, such as ammeters and voltmeters. This type of construction would probably cover only units using natural ventilation, as fan-cooling becomes more involved for assembly on the job.

The type of equipment just described to operate from 115 volts also lends itself well where power is purchased and metered at each rectifier. This power can usually be purchased from a public utility that has such power lines already installed.

The selection of the size of the unit must be decided on the basis of local conditions. A look at com-

parative costs of factory-assembled units of various ratings may be of some help. These prices may not be accurate for a general over-all estimate, but the comparative value between units of similar quality and construction will still hold.

A small unit using natural cooling of about 100-watt capacity will cost in the neighborhood of \$1.30 per watt. A fan-cooled unit of 200-watt capacity will cost about 90 cents per watt. Another fan-cooled unit of 400-watt capacity will cost about 60 cents, and a large unit of 1600 watts will cost in the neighborhood of 30 cents per watt. From this comparison, the economy of the large units are easily justified from the construction standpoint. However, from the practical standpoint, this capac-

ity should be balanced against the protection obtained from a large unit as compared with the protection from a number of smaller units at greater cost.

Figures 18, 19 and 20 show a special design of copper-oxide assembly developed for Ford, Bacon and Davis, and used originally on a cathodic protective system for the Interstate Natural Gas Company in Louisiana.

The nature of the terrain and the prevalence of high water during the rainy season necessitated locating the equipment well above ground level. The casings mounted on the cross-arms contain only the rectifier stacks. These stacks were fed directly from an oil-cooled transformer, which operated from a 2300-volt line carried on the company-owned pole line which extended along the right-of-way of the pipeline.

Either one or two rectifier assemblies were used at a location, thus permitting a selection of 25 or 50 amperes maximum. The distributed ground system developed by Ford, Bacon and Davis permitted the rectifiers to be operated at 5 volts d-c or less, to maintain a minimum negative voltage of 0.25 volt on the pipe, and thus obtain a remarkably high operating efficiency.

The right-of-way was generally North and South through swamp-land and woods, subjecting the rectifiers to the direct rays of the sun. A special double-wall casing was developed to utilize the sun's heat to promote air circulation. A small indicator lamp, behind a colored bulls-

eye, facilitated inspection from the ground.

The record of operation of this system for the past twelve years speaks well for the engineering that went into the project initially, and the general effectiveness of copper-oxide for this type of service. In passing, it is interesting to note that one exceptionally high flood submerged many of the rectifier units. The maintenance crew made the rounds in rowboats, removed the rectifier stacks, baked them out in an oven, and eventually put a large percentage of them back in service, much to the astonishment of the manufacturer, who had said that "it just couldn't be done."

Figures 20 and 21 show a 1640-watt copper-oxide rectifier of the fan-cooled type installed on a pipeline. This rectifier represents another type of installation problem where power is purchased locally, and the rectifiers must be distributed along the pipeline with a view to availability of power rather than to efficiency of operation.

By comparing the three-unit, convection-cooled assembly of 250-watt capacity with this 1640-watt, single unit, fan-cooled assembly, shows up the effectiveness of fan cooling in saving of size and weight.

These installations illustrate two of the many problems that must be considered in a cathodic protection system. They also show the adaptability of copper-oxide in solving these problems. These installations have given 12 years of satisfactory service, ample testimonial to the adaptability of copper-oxide rectifiers in this particular field.

## Corrosion—News Section

### PERSONALS

**Dr. Harold F. Haase** has accepted the position of Professor of Metallurgical and Chemical Engineering at Marquette University, Milwaukee, Wisconsin. Prior to joining the Marquette faculty, Professor Haase was associated with the Batelle Memorial Institute in the Corrosion Division. Some of his recent work was associated with the Natural Gasoline Association's Condensate Well Corrosion Committee, and with a project on corrosion of air-driven oil wells for the Pennsylvania Grade Crude Oil Association. He has been actively engaged in the corrosion field for the past 20 years. One of his early associations was with the A. O. Smith Company of Milwaukee. Professor Haase was then engaged in soil corrosion, cathodic protection problems and other phases of the oil and gas pipeline corrosion problems. Dr. Haase, who holds the degree of Doctor of Philosophy, was engaged in the consulting field during the latter part of 1930. Besides his duties in the teaching field, he hopes to accept a limited number of consulting clients.

**Frank X. Karle** has been appointed treasurer of the Aluminum Industries, Inc., Cincinnati, Ohio, succeeding Harry J. Hater, who retains the office of president and general manager.

**Lawrence J. Jones** has been named purchasing agent for the Ashland, Kentucky, division of the American Rolling Mill Company, Middletown, Ohio, succeeding the late C. J. Moeling.

**Henry W. Parker** has been selected to fill the newly created position of technical advisor for the Sylvania Electric Products, Inc., New York. Mr. Parker is now working in coöperation with the United States Department of Commerce, Office of Technical Services, Technical Industrial Intelligence Division, in the study of electron tube developments made by Germany and Japan during the war. Prior to joining Sylvania, Mr. Parker was associated with General Electric, Schenectady, N. Y.

**Clarence H. Sample** has joined the electroplating section of the International Nickel Company, Inc., New York. Mr. Sample was formerly with the Bell Telephone Laboratories, New York.

**Lloyd E. Tracy** has been elected vice president of the Oil Well Supply Company, Dallas, Texas, a subsidiary of the United States Steel Corporation. Mr. Tracy retains the position of general manager of sales for the company.



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**Francis J. Wakem** has been appointed vice president of the Johns-Manville Sales Corporation, a subsidiary of the Johns-Manville Corporation, New York. He will continue as merchandise manager.

**Dr. R. B. Mears**, formerly associated with the Research Laboratory of the United States Steel Corporation of Delaware in Kearny, New Jersey, is now with the Research Department of the Carnegie Illinois Steel Corporation, Pittsburgh, Penna., a subsidiary of U. S. Steel.

**James P. Gill**, vice-president of Vanadium-Alloys Steel Co., Latrobe, Pa., and **Herbert R. Hanley**, professor emeritus of metallurgical engineering at the School of Mines and Metallurgy, University of Missouri, have received honorary degrees of Doctor of Engineering from the Missouri School of Mines.

**Clyde E. Williams**, director of Battelle Memorial Institute, was elected president of the American Institute of Mining and Metallurgical Engineers for 1947.

**L. A. Lindberg**, president of the Lindberg Steel Treating Co., Chicago, has been elected president of the Metal Treating Institute. **R. G. Sault**, Porter Forge & Furnace Inc.,

Boston, was elected vice-president; **R. W. Thorne**, treasurer; **Stewart N. Clarkson**, executive secretary; and **J. R. MacAllister**, Syracuse Heat Treating Co., assistant secretary.

**H. E. Hall**, president of the Metals Disintegrating Co., Elizabeth, N. J., has been re-elected president of the Metal Powder Association; **S. K. Wellman**, president of the S. K. Wellman Co., was re-elected vice-president; and **F. E. Wormser**, re-elected acting secretary-treasurer.

**A. B. Kinzel**, vice-president of the Union Carbide and Carbon Research Laboratories, Inc., and of the Electro Metallurgical Co., has been re-elected chairman of the Engineering Foundation.

**Humble Oil and Refining Company** announced the following changes in supervisory forces: **C. G. Swank**, assistant superintendent, Conroe district, transferred to the Thompson district as acting superintendent; **W. W. Thames**, Anahuac district, Monroe City, Texas, has succeeded Mr. Swank in the Conroe area; **A. R. Bruce**, promoted to assistant district superintendent of the Tomball, Texas, district, and **J. A. Mangum**, promoted from senior gas engineer to assistant superintendent of the cycling plant, Katy, Texas.

## NEW PRODUCTS

**E. F. Houghton & Company**, Philadelphia, announced a new line comprising seventeen different chemical cleaning products, to be known as the Houghto-Clean 200 Series. The line includes cleaners for maintenance work, ferrous and nonferrous metals for use prior to painting and enameling; electrolytic cleaners and special purpose compounds.

**An Aluminum Brazing Flux**, said to possess qualities that make it possible to braze 2S, 3S, 53S and 61S aluminum when used with Airco No. 26 wire, has been placed on the market by the Air Reduction Sales Company, New York. The new flux will be known by the trade name of "Elite".

**Oakite Products, Inc.**, New York, has marketed a material which, the company claims, reduces fuming, hydrogen embrittlement and discoloration of work, for inhibiting hot sulphuric acid pickling solutions. Called Oakite Pickle Control No. 3, the material, a yellowish-brown powder, can also be used in mixed sulphuric-hydrochloric baths in which sulphuric predominates. It is claimed that the new material saves metal, acid and maintenance costs, and minimizes the frequency and cost of spent liquor disposal by retarding the build up of iron sulphate in solution.

**Plastic Engineering & Sales Corp.** announced a line of Plastic Ring Seal Gaskets for particular use in the oil and gas industry. Known as Pesco Plastic Seal Rings, these gaskets are made of Fiberglas and a special synthetic resin molded under high pressure and temperature. It is claimed that these rings are unaffected by any of the gases or fluids encountered in oil and gas production or transmission and that they have the following advantages over metal ring gaskets made of forged steel or alloy material:

- 1) The plastic ring will eliminate corrosion at the joint due to dissimilar metals in the presence of an electrolyte. Alloy rings increase the rate of this type of corrosion although the effect is transferred to the body of the flange.
- 2) The Pesco ring will stand a great deal of rough handling and still make a perfect joint under high pressure. When the surface of metal rings are nicked or marred by rough handling they must be re-machined or replaced with new rings.
- 3) The plastic ring makes it possible to electrically insulate ring seal joints by using insulating sleeves and washers around the flange studs. A great deal of casing corrosion due to long line galvanic cur-

rents can be eliminated by insulating all well structures at the Christmas tree.

The new plastic ring will be manufactured in all sizes to replace any metal ring fabricated to API specifications 5-G-3. Further information may be obtained from Plastic Engineering & Sales Corp., P. O. Box 1037, Fort Worth, Texas.

**The development of rolled nickel and Monel-clad strip** was announced by the Superior Steel Corporation, Carnegie, Pennsylvania. This composite strip is available in widths between one-quarter of an inch and ten and one-quarter inches, in coils ranging up to several hundred feet depending upon gauge. In the cold rolled condition, it is produced in thicknesses between 0.010 and 0.125 of an inch. In the hot rolled condition, it is available in thicknesses between 0.095 and one-quarter of an inch. Depending on requirements, the clad strip is furnished with cladding on one side only or on both sides. The standard cladding thickness is 10 percent of the total thickness, which means that on the single clad strip the nickel or Monel would represent ten percent of the total thickness and the steel 90 percent. On double clad strip the three layers would be 10 percent nickel or Monel, 80 percent steel, and 10 percent nickel or Monel.

It is claimed to be impossible to separate the nickel or Monel cladding from the steel base by any other means than the chemical dissolving out of the steel from the cladding. Separation cannot be effected by mechanical means or by heating. Because of this fact, the clad strip can be stamped, drawn, spun, bent, spot-

welded, or otherwise fabricated in the same manner and with no more difficulty than ordinary low carbon, deep-drawing steel.

Because the thermal coefficient of expansion of nickel, Monel and steel are nearly the same, there is little danger of warping or twisting in applications where temperature changes are encountered.

**Trimount Instrument Company** claims to have developed a cathodic unit that stops rust and corrosion by eliminating electrolytic action on metal being protected. Flow of current in tanks or pumps being protected is reversed in the usual manner by introduction of a cathode which is charged by a rectifier. By this method, the structure being protected becomes the cathode instead of an anode, and is no longer subject to corrosion or rust from electrolytic reaction. The unit is contained in a weatherproof steel cabinet, and has a dc output capacity of from 2 to 5 amperes at 31 to 50 volts, which is equivalent to from 100 to 150 watts, and sufficient to protect submerged structures up to 10,000 square feet. Further information can be secured by writing the manufacturer at 37 W. Van Buren St., Chicago 5, Illinois.

**Ampco Metal, Inc.**, Milwaukee, Wis., has placed on the market a coated beryllium-copper welding electrode which, it is claimed, possesses a flux coating quality that stabilizes the arc and flux oxides formed in welding operations. Known as Beryl-Trode, the electrodes are reported to produce a dense deposit and can be used with either metallic or carbon arc welding.

**Production of stainless steel laboratory filters with porous stainless steel filter elements** is announced by the Micro Metallic Corporation, 193 Bradford Street, Brooklyn 7, N. Y. These filters are available through laboratory supply houses. This line of filters includes filter crucibles, Buchner funnels, gas dispersion tubes and filter tubes.

These laboratory filters are made up by welding the porous stainless steel filter element into carefully designed solid stainless steel filter bodies. It is claimed that in addition to freedom from breakage, the filters show a number of other advantages. They can be heated and cooled without danger of cracking. They are light and uniform in weight. Higher flow rates for any given pore size are obtained than with other types of filters. In addition to resistance to many acid conditions, the funnels are normally used without a paper covering, but the coarser grades may also be covered with a filter paper, under which conditions higher flow rates are obtained than with perforated Buchners, since the whole area of the filter paper is utilized, rather than the section just above the holes. Availability of industrial filter units made up with the same filtering material is a great advantage in the application of the new filters to research and development work. The

filter crucibles may be used for the gravimetric analysis of all the common elements. Filter crucibles and Buchner funnels are also useful in accomplishing separations. Gas dispersion tubes are constructed in such a way that the whole volume of liquid may be filled with fine bubbles. The filters are available in five porosities ranging from very fine to very coarse.

**Relaxing of the use of Saran film**, type M, for military packaging has made moderate quantities of it available again, The Dow Chemical Company announced. The film is a tough, flexible, one-ply, transparent material with extremely high resistance to water and moisture vapor transmission.

As container liners for shipping solid chemicals, acids, organic materials and hygroscopic products, this type M Saran film is especially well suited because of its chemical and acid resistance. Dow states that the film is available in seamless tubes ranging from 6 to 32 inches in size and in increments of two inches. In using the tubes for container liners it is only necessary to tie one end and place in the container before filling. The top of the tube is then tied before container cover goes on.

Dow also stated that there has been a reduction in the price of Saran film.



## GENERAL INTEREST

**James T. Gow**, of Battelle Memorial Institute, Columbus, Ohio, will be one of four speakers who are scheduled to deliver papers during the General Industry Symposium at the Chicago Conference and Exhibition sponsored by the NACE at the Palmer House in April. Mr.

Gow will discuss "Oxidation of Stainless Alloys," dealing with the high-temperature gas-atmospheric corrosion of Fe-Cr-Ni alloys.

In his discussion, Mr. Gow will go into the techniques in use for conducting and evaluating the results of elevated-temper-

ature gas-atmosphere corrosion tests, both service tests and simulated service tests, including accelerated testing.

He will also bring out the need for standardization of the techniques for conducting such corrosion tests and the reporting of data to allow a satisfactory correlation of data obtained by various investigators.

The corrosion data available in the literature and considered of value in disclosing certain relations will be brought together and correlated to give a general picture of

the effect of the various elements added to the Cr-Ni-Fe heat-resistant alloys upon corrosion resistance in various ambient atmospheres, and especially in air and flue gases.

Other physical and mechanical properties to be given consideration in selecting heat-resistant alloys for structural uses at elevated temperature; present trends and probable future developments are to be discussed.

Mr. Gow, who holds the M.E. and M.S. degrees from the University of Minnesota, also attended the Loop Training Course of the Bethlehem Steel Company. He was Research Assistant in the Department of Metallurgy at the University of Minnesota in 1928, and after receiving his M.S., joined the faculty of Purdue University as an instructor in Metallography and Fire Assaying. From 1929-30, he was at the Naval Research Laboratory, Anacostia, D. C.

From 1930 to 1936, he was metallurgist at the Research Laboratory of the International Nickel Company, Bayonne, N. J., and joined the Battelle Memorial Institute in 1936. He has been actively engaged in conducting and supervising research work on the physical, mechanical and chemical properties of heat-resistant alloys since 1930. The results of much of his work have appeared in technical literature and in bulletins of the Alloy Casting Institute.



**James T. Gow**

**Norman Hackerman**, Associate Professor in the Department of Chemistry, University of Texas, will be a fellow speaker with Mr. Gow before the General Industry Symposium. Dr. Hackerman's subject will be "Mechanism of Inhibitor Action," during which several recent theories



**Dr. Norman Hackerman**

of inhibition as well as the basis for a new theory will be discussed.

It will be Dr. Hackerman's contention that:

"The introduction of chemicals into corrosive media as a means of retarding the rates of metal dissolution and converting from localized to generalized corrosive attack is

widespread. Such use at present is based to a large degree on empirical knowledge and trial and error methods of testing. That in order to choose a proper inhibitor more effectively, a general theory of corrosion inhibition is required. On the basis of such a theory, the search for an inhibitor could be limited at once to a type of compounds, or at most a few types. Furthermore, decisive laboratory testing methods can be devised which depend on one or two fundamental properties of the materials in question. Thus a relatively small group of materials could be screened quickly to provide the best inhibitor for the purpose intended."

Dr. Hackerman will also point out that "even when an apparently useful inhibitor is found, it is necessary

to consider carefully the chemistry of the system in its effect on the inhibitor. The principal requirement is that the inhibitor remain in the form in which it is most effective. Moreover, it is shown that a material which is capable of acting as an inhibitor under certain conditions is equally capable of acting as a corroding agent or a corrosion promoter under other conditions."

Data on the use of a number of inhibitors under actual operating conditions, in both anaerobic and aerated systems, will also be presented.

Dr. Hackerman has long been interested in the study of inhibitors. During the past two years, he has been directing some studies on corrosion in natural gas condensate wells under the sponsorship of the Natural Gasoline Association of America, with whom the Gas Condensate Well Committee of the National Association of Corrosion Engineers works in collaboration, and also some fundamental studies on corrosion inhibitors under a contract with the Office of Naval Research.

Born in Baltimore, Dr. Hackerman received both the A.B. and Ph.D. in chemistry from Johns Hopkins University, the latter in 1935. For four years following receiving his Ph.D., he was research chemist with the Colloid Corporation, and at the same time teaching physical chemistry at Loyola College, Baltimore. He spent the next year and a half in the U. S. Coast Guard Laboratory, leaving there to join the chemistry staff at the Virginia Polytechnic Institute. After three years, he obtained a leave of absence to work for the Kellogg Corporation on the Manhattan Project. In 1945, he

joined the faculty of the University of Texas.

**Mr. George McComb**, Allied Chemical Company, Barrett Division, who is chairman of the Regional Management Committee of NACE, announced officers had been elected in four of the five recently established Regional Divisions of the Association. The newly appointed officers, together with Directors in each region follow:

#### NORTH CENTRAL REGION

Regional Director—Hugh J. McDonald, Illinois Institute of Technology, Chicago, Ill.

Chairman—Lyman F. Greve, Commonwealth Edison Company, Chicago, Ill.

Vice Chairman—Harold A. Robinson, The Dow Chemical Company, Midland, Mich.

Secretary - Treasurer—H. A. Ronningen, Ronningen Engineering Sales, 1803 Chicago Ave., Evanston, Ill.

Trustee in lieu of past chairman—Charles A. Mann, chairman, Department of Chemical Engineering, University of Minnesota, Minneapolis, Minn.

#### SOUTH CENTRAL REGION

Regional Director — L. F. Scherer, Texas Pipe Line Co., Houston, Texas.

Chairman — A. N. Horne, Texas-Empire Pipe Line Co., Tulsa, Okla.

Vice Chairman — Derk Holsteyn, Shell Oil Co., Houston, Texas.

Secretary - Treasurer—T. P. Kelley, James E. Mavor Co., 514 M & M Building, Houston, Texas.

Trustee in lieu of past chair-

man—Starr Thayer, consulting engineer, Houston, Texas.

#### NORTHEAST REGION

Regional Director — Robert Pope, Bell Telephone Laboratories, New York, N. Y.

Chairman—Dr. John M. Pearson, Swarthmore, Penna.

Vice Chairman — A. S. Brookes, Public Service Electric & Gas Co., Newark, N. J.

Secretary - Treasurer — F. R. Arnoldy, American Telephone and Telegraph Company, 195 Broadway, New York 7, New York.

Trustee in lieu of past chairman—Harry A. Jordan, American Water Works Association, New York.

#### WEST COAST REGION

Regional Director — F. A. Hough, Southern Counties Gas Co., of California, Los Angeles, Calif.

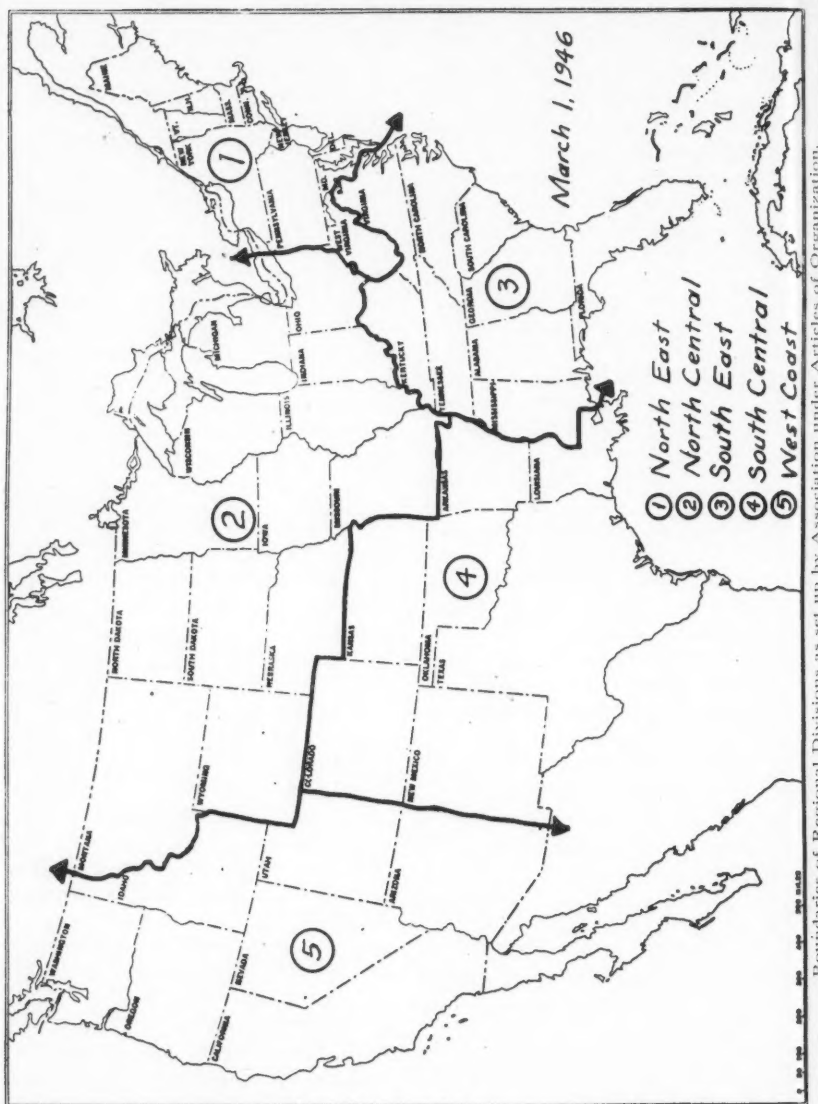
Chairman — V. N. Jenkins, Union Oil Co., Wilmington, Calif.

Vice Chairman — D. Blackburn, Pasadena Water Department, Pasadena, Calif.

Secretary - Treasurer — Guy Corfield, Southern California Gas Co., P. O. Box 3249, Terminal Annex, Los Angeles 54, Calif.

Trustee in lieu of past chairman—R. R. Ashline, Department of Water & Power, Los Angeles, Calif.

NACE members in the South Central Division were scheduled to meet in Atlanta and vote on Regional officers at the time Mr. McComb made this report.



In the South Central Region, it was voted to form a Section for those members of NACE who reside in the Houston area. The meeting was held November 19 in the Bayou City, and Mr. L. Scherer, of Texas Pipe Line of Houston, presided. The following officers were elected:

Chairman, W. P. Noser, Humble Pipe Line Company, Drawer 2220, Houston, Texas; Vice Chairman, C. L. Morgan, United Gas Corporation, Box 2628, Houston, Texas; Secretary-Treasurer, E. L. Moseley, South Chester Tube Company, 904 Esperson Building, Houston, Texas.

About 100 persons attended the meeting, and much interest was manifested. Those present included F. J. McElhatton and G. E. Olson, president and vice president, respectively, of NACE; and Dr. R. B. Mears, Robert Pope, Arthur Smith, Jr., Tom Holcombe, O. C. Mudd and Ivy M. Parker, directors in NACE.

A meeting of the new Section of Division Four will be held this month, at a place and time to be announced.

**Office of Research and Invention,** U. S. Navy, is sponsoring a fundamental research project at the Ohio State University's Corrosion Laboratory, which will be under the direction of Professor M. G. Fontana. The Navy is imposing no restrictions on details of research method.

**Arizona Pipe Line Co.,** Amarillo, Texas, is planning to construct a 600-mile, 8-inch crude pipeline between Amarillo and Phoenix, Ariz., to cost approximately \$8 million.

**Ontario Hydroelectric Commission,** Toronto, Ont., Canada, is plan-

ning to construct two dams and plants to generate 80,000 horsepower, costing \$10 million.

**Dow Chemical Company,** Midland, Mich., has acquired four sites in the Velasco-Freeport, Texas, area from the government for approximately \$36 million. Dow expanded their plant in Freeport with the acquisition, for increased production of magnesium and allied chemical derivatives from water.

**Temperature range** of present-day commercial interest extends from 500 to 1800° F., C. L. Clark, research metallurgical engineer of the Timken Roller Bearing Co., Steel and Tube Division, told the Washington Chapter of the American Society for Metals at a recent meeting, in a comprehensive review of the high temperature applications of steels. Corrosion resistance is the primary concern up to 750° F., corrosion resistance and strength at 750 to 1250° F. and strength and oxidation resistance at 1250 to 1800° F., he said.

Various steels which have been developed to meet the different requirements of service were considered, and the relevant advantages and disadvantages of each were discussed. In selecting a steel for a given application, consideration should be given to the following factors: (a) expected life, (b) temperature and pressure, (c) permissible deformation, (d) hazards involved if failure should occur, and (e) cost and availability.

In conclusion, Dr. Clark described the hot twist test for determining the best temperature range for the hot processing of steels, particularly the higher alloy types.

## NEW LITERATURE

*Water Treatment and Purification*, by William J. Ryan; McGraw Hill Book Company, Inc., New York, N. Y., 1946, 270 pages, \$2.75.

This revised manual covers all processes on the subject of water purification. It contains much new material, including facts relating to impurities in water and the problems they present, treatments required for waters used for different purposes, construction and operation of apparatus for applying each process, chemical reactions that take place in the various processes. The subjects of Sedimentation and Coagulation, Ion Exchangers, Filtration and Prevention of Corrosion are also covered.

*Shot Peening*, American Wheelabrator & Equipment Corp., Mishawaka, Ind., 1946, 128 pages.

Provides a complete and detailed explanation of the process for the use of engineers and production men who are actively interested in the application of shot peening. It describes the applications and advantages of shot peening, the equipment and procedures involved, and the theory of prestressed surfaces in relation to shot peening. Subjects covered are: fatigued resistances and benefits of shot peening, test strips, equipment, applications for the airless and air blast methods, and type of shot.

*Physical Constants of Hydrocarbons, Volume III*, by Gustav Egloff; Reinhold Publishing Corporation, New York, 1946; 661 pages. A collation and evaluation of all melting-point, boiling-point, density, and refractive-index data available up to May, 1944, concerning hydrocarbons.

*Encyclopedia of Hydrocarbon Compounds*, compiled by John E. Faraday; Chemical Publishing Company, Inc., Brooklyn, 1946; various paging. An extensive encyclopedia of the hydrocarbons, in loose-leaf form.

*Welding Aluminum and Aluminum Alloys*; Reynolds Metals Company, Inc., Louisville, Ky., 1946; 87 pages.

An explanatory handbook presents production methods recommended by the Reynolds Metals Company with regard to welding aluminum and its alloys. It describes the following specific processes: gas welding; metal-arc welding; carbon-arc welding; atomic-hydrogen arc welding; inert-gas-shielded arc welding; resistance welding; spot welding; seam welding; flash welding. Other processes treated include brazing aluminum; furnace brazing; torch brazing; and soldering aluminum. Tables list mechanical properties of sheet metals, welding data for hand and machine work, and strength figures for welded aluminum alloys. Photographs show a wide variety of welding operations and applications.



## Corrosion Abstracts

### ATMOSPHERIC CORROSION

**Tropical Moisture and Fungi; Problems and Solutions.** E. S. McLARN, H. OSTER, H. KOLIN & A. NEUMANN, *Electrical Communication*, **22**, No. 4, 303-313 (1945) *Corr. & Mat. Prot.*, **3**, N. 3, 24 (1946) Mar.

Outlines experiences with failures of radio and wire communication equipment in hot, humid climates; tropical conditions; organic matter present; government procurement measures; and program of the Federal Telephone and Radio Corp. Moisture is the most serious direct cause of trouble in the tropics. Among other difficulties it causes corrosion of metals in the equipment.

### BEARING CORROSION

**Practical Information Concerning Steam Turbine Lubricating Oil.** S. F. WHIRL, *Duquesne Light Co., Pittsburgh, Pa., Power Plant Eng.* **50**, No. 6, 64-67 (1946) June.

Corrosive qualities of oils acting on metal are illustrated, and corrosion prevention methods which have been used, enumerated.

### BOILER CORROSION

**Some Cases of Corrosion in Engineering Practice.** G. W. BOND & G. H. STANLEY, J. of the South African Institution of Engrs., **43**, 112-115 (1945) Feb.-Mar.; **44**, 3-5 (1945) Aug.-Sept. *Corr. & Mat. Prot.*, **3**, No. 1, 25 (1946) Jan.

Part of the discussion and author's reply to the discussion of the paper by Stanley in the J., **42**, April-May, 1944. Describes experiments which indicate that painting insides of boiler drums with graphitic paint does not protect from corrosion and may be dangerous if not applied as a continuous and adherent film.

### CATHODIC PROTECTION

**Economics and Effectiveness of Cathodic Protection on Large Diameter Pipelines.** N. K. SENATOROFF, *Gas*, (1946) 41-43 July.

What either cathodic protection or pipeline wrapping alone might fail to accomplish in protecting a pipeline from corrosion, a combination of both might do. This is exemplified in a report on the experience of the Southern Counties Gas Co. of Calif., in trying to defeat corrosion in a 26-inch high-pressure natural gas transmission line in San Joaquin County. In 1941, the line, then ten years old, was leaking to such an extent that a study was undertaken to find a means of reducing repair costs sufficiently to keep the line in operation for several more years. Drainage stations were decided on as an experiment, and the first one was installed in October of that year, with the second being erected in January, 1943. Studies were made of the results, which were found not to be up to expectations, because the

electrolytic damage to the line prior to the installation of cathodic protection had been so extensive that there existed numerous pits in the pit which had actually perforated the pipe wall. So reconditioning of the pipe was tried, with considerable emphasis being placed upon the thickness of the protective material used. The results to date are reported in this article.—G.P.C.

**Cathodic Protection of Metals.** Review from *Technische Rundschau*, May 17 and May 24, 1946. *Light Metals*, **9**, 378-380, 382 (1946) July.

Emphasis is laid on need for adequate assessment of prevailing conditions before adopting one or other of available protective systems.—B.L.R.

**Use of Magnesium Anodes for Cathodic Protection.** L. M. OLDT, *Corr. & Mat., Prot.* **3**, 12-14 (1946) June-July.

Discusses use of magnesium anodes in protecting pipelines and other buried structures.—B.L.R.

**Cathodic Protection on Large Diameter Pipelines.** N. K. SENATOROFF, *Gas Age*, **98**, 18-19, 56-57 (1946) July 25.

From the cost study given of coating material involved in providing an additional 1/32-inch thickness of enamel to the 3/32-inch average thickness, occasionally specified as satisfactory coating requirement, it is quite apparent that the extra cost is fully justifiable. An expenditure of approximately \$200 per mile on a 26-inch line for the improvement of the protective value of the coating is being gradually refunded.—B.L.R.

## CHEMICAL CORROSION

**Furan Resins in the Plating Industry.** WILLIAM H. ADAMS, JR., *Monthly Review*, **33**, 830-832 (1916) Aug.

Value of furan resins to the electroplater lies in the fact that equipment can be made from it which will resist the corrosive effects of practically every plating solution except chromium. Such equipment, including tanks, pumps, pipe and fittings, valves, etc., make it possible to avoid completely the danger of damage by corrosion.—B.L.R.

**Corrosion-Resistant Alloys.** Steel, **119**, 70-75, 112 (1946) July 29.

Four metals finding wide use in industries which handle such reactive acids as boiling hydrochloric, sulphuric, and hot nitric are described and their range of application indicated.—B.L.R.

**Corrosion Limits Metals That Can Be Used for Construction of HF Alkylation Units.** *National Petroleum News*, **38**, R618 (1946) Aug. 7.

Presents a summary of tests on the corrosion of metals by hydrofluoric acid, and correlates the data with actual experience in commercial operations. The material was originally published as Chap. 10 of the recent book, "Hydrofluoric Acid Alkylation."—B.L.R.

**Metals and Alloys in the Chemical Industry.** M. G. FONTANA, Ohio State University, Paper before ASM, Baltimore Chptr., Mar. 18, 1946. *ASM Metals Review*, **19**, No. 5, 5 (1946) May.

Corrosion is classified in types. In discussing erosion corrosion phenomena, failure at an elbow in a

pipeline handling return condensate due to impingement when fluid is in motion is cited.—I.N.C.

#### White Hope from Green Mould.

Process Industries Quarterly, **8**, No. 4, 2-3 (1945), Nickel Bull., **19**, No. 1/2, 5 (1946) Jan.-Feb.

Nickel and high nickel alloys are among the few metals which have been found to be entirely safe in contact with penicillin. These materials form no harmful corrosion products, nor is there any dangerous chemical reaction with the sensitive penicillin solutions. Nickel and its alloys have the further advantage of high strength, ductility and workability, characteristics which are significant in the production of all large-scale chemical plants. Among the uses of nickel alloys in this field, specific reference is directed to the satisfactory service of Inconel tank linings and temperature-control coils, and to the use of nickel and Monel filters in the removal of pyrogens from penicillin solution. In the drying stage, vacuum pumps of special design are used to extract the moisture from the frozen solution. In these pumps, vital parts such as valve discs and springs are made from Monel and "K" Monel.

**Metal Corrosion Under Conditions of Intensive Production of Sulfuric Acid in Towers.** S. D. STUPNIKOV, Khimicheskaya Prom., No. 2, 9-11 (1945) Chem. Abs., **40**, 2097 (1946) Apr. 20.

Corrosion of lead, cast iron, and steel in 6, 9, and 12 percent nitric acid, and 76.6 percent and 80 percent sulfuric acid at 70° and 110° was investigated by determining loss of weight in unit time and calculat-

ing from the results mm. of depth per year. The corrosive effect of nitric acid on lead increases with concentration; that of sulfuric acid is nearly constant with increasing concentration at 70°, and decreases with concentration at 110°. A protective passive film formed on the metal is firmer at 110° than at 70°. Cast iron and steel were affected less than lead under all the conditions of the experiments. Thus, subject to a study of the behavior of these metals in gaseous corrosive media, it appears that lead is sufficiently resistant to warrant its use in towers for intensive sulfuric acid production, while cast iron and steel are completely resistant.

**Sulphur Compounds in Combustion.** A. DOOLEY, Inst. Fuel War Time Bull., 30-33 (1945) Oct. Brit. Abs., **BI**, **9** (1946) Jan.

Relevant literature published since 1939 is reviewed. Discussion includes action of sulfur compounds on materials used in boiler construction and effects on sulfur compounds in metallurgical furnaces.

**New Micrographic Applications of Corrosion Figures on Refined Aluminum.** P. LACOMBE & L. BEAUGARD, Compt. rend., **219**, 66-68 (1944); Chem. Abs., **40**, 2098 (1946) Apr. 20.

After attack by 1/3 hydrochloric acid, 1/3 nitric acid, 1/3 water, 2 HF, simultaneous examination of corrosion figures, glide lines, and their relative disposition permits specification, in certain simple cases, of the crystallagraphic orientation of the micrographic surface of aluminum (99 percent) without resorting to X-rays.

**Descaling of Steel by Acid Pickling.** V. O. KRENIG and YE. M. ZARETSKI, *Korrosion und Metallschutz*, **17**, No. 7, 243-246 (1941).

Pickling of scaled 1 percent chromium 0.13 percent copper, 1 percent manganese steels in 10 percent sulfuric acid solution was investigated. The nature of the pickling process is analyzed. Evolution of gaseous hydrogen does not take place on scale but at the anode. Influence of anode potential vs. cathode potential on descaling process, the three-electrode cell active in pickling, and comparative weight losses of anode and cathode are discussed. A graph shows electrode potential of a chromium-manganese-silicon steel in 10 percent sulfuric acid.

#### COATINGS

**Wetting of Steel Surfaces by Esters of Unsaturated Fatty Acids.** N. F. MILLER, *J. of Phys. Chem.*, **50**, 300-319 (1946) July.

As part of a general investigation of adhesion of paint coatings to steel, wetting properties of a series of pure esters of common unsaturated fatty acids toward polished 48-S-5 armor plate were measured by means of contact angles. Discussion is given of significance of different contact angles. Dynamic receding angle is shown to be the fundamental criterion of film stability. "Work of adhesion" is shown to involve a force whose magnitude and effects are determined by dynamic receding angle. Experiment demonstrating this point is described. From standpoint of adhesion of paint films to steel, it appears that contact-angle values measure a more fundamental wetting property than work of adhesion values, since contact angles

apparently determine the ability of a paint to displace absorbed air or moisture films from steel. Fifteen ref.—B.L.R.

**Protective and Decorative Coatings for Metals.** A. F. BROCKINGTON, *Sheet Metal Industries*, **23**, 1355-1362 (1946) July.

General review of metal finishing processes.—B.L.R.

**Action of Antifouling Paints. Solubilities of Antifouling Toxics in Sea Water.** JOHN D. FERRY and GORDON A. RILEY, *Ind. & Eng. Chem.*, **38**, 699-701 (1946) July.

The solubilities in sea water of various copper and mercury compounds which have been proposed as antifouling toxics cover a very wide range. Cuprous oxide, the toxic which has been most widely used, has a solubility of 5.4 micrograms of copper per cc., high enough to be effective but not so high that its leaching rate from antifouling paints is too difficult to control. Fifteen ref.—B.L.R.

**Flame Fusing Protective Coatings.** *Western Machinery and Steel World*, **37**, 113-115 (1946) July.

Minimum coat applied by Glaspay is about six ounces per square foot, but beyond this it can be piled on to any thickness. Chief advantages claimed: comparative speed with which surfacing can be carried out; large areas and heretofore inaccessible surfaces can be coated; greater thickness that can be applied in areas subjected to severe corrosive attack; wide variety of metals that may be sprayed; and finer surface appearance.—B.L.R.

**Some Properties and Applications of Aluminized Steel.** Modern Metals, **2**, 14-16 (1946) Aug.

Material has advantages over zinc, tin or lead coatings on steel, in that resistance to corrosion, heat and oxidation is superior. Material is attractive, strong and has excellent heat reflectivity. Describes some of these properties, the welding technique and some typical applications.—B.L.R.

**Special Organic Coatings for Protection Against Corrosion.** RAYMOND P. DEVOLUY, Paint, Oil & Chem. Review, **109**, 12 (1946) Aug. 8.

Discusses special coatings with particular reference to their use in the marine field, with principal emphasis on U. S. Navy hot plastic antifouling paint.—B.L.R.

**Finishing Clinic.** ALLEN G. GRAY, Products Finishing, **10**, 74-76 (1946) Aug.

Finishing zinc alloy die castings; buffing and polishing magnesium; influence of surface structure of steel on quality of galvanized coatings; protection of workers against solvent health hazards; effect of cleaning on the corrosion of steel; selection of baking oven for organic finishes.—B.L.R.

**Water Immersion Testing of Metal Protective Paints.** W. W. KITTELBERGER and A. C. ELM, Ind. & Eng. Chem., **38**, 695-699 (1946) July.

Paint system consisting of one coat of zinc chromate primer and one coat of low gloss, alkyd hull paint was applied to various sub-

strate materials and immersed for varying periods of time in distilled water and in solutions of sodium chloride and sucrose with osmotic pressures of 6 to 30 atmospheres. Rate and degree of water absorption and blistering were determined by extensive measurements of weight and volume changes, and by visual examination. Results given.—B.L.R.

**Neoprene Linings for Chemical and Corrosion Protection.** G. A. RONSEN, Corr. and Mat. Prot., **3**, 8-11 (1946) July.

Neoprene is much more resistant than natural rubber to the deteriorating effects of oxidation, sunlight, moisture, and swelling in organic liquids. Basic ingredients incorporated into the lining. Modifications of the chemical and physical properties of the lining materials for specific service conditions are effected by varying the ratio of Neoprene to carbon black, and the type and concentrations of the accelerators, antioxidants, and plasticizers used.—B.L.R.

**Inactivation of Highly Pigmented Antifouling Films Applied to Steel.** A. L. ALEXANDER and R. L. BENEMELIS, ACS 110th Mtg. Chicago, Sept. 9-13, 1946, Abs. of Papers: 1-2N.

Experimental data are presented which indicate that above pigment-volumes of 25 percent copper flake and copper powder antifouling paints are likely to be inactivated when applied to steel surfaces, with a resulting acceleration in the rate of corrosion of the steel to which they are applied.

**Water-Immersion Testing of Metal Protective Paints. Role of Electroendosmosis in the Water Absorption and Blistering of Oil Paints.** W. W. KITTELBERGER and A. C. ELM, New Jersey Zinc Co., A.C.S. 110th Mtg., Chicago, (Sept. 9-13, 1946) Abs. of Papers: 3-4-N.

It was previously shown that the rate and degree of water absorption of a paint system immersed in water or aqueous solutions are functions of the solute concentration gradient set up across the face of the coating. When an electrical potential gradient is superimposed upon a solute concentration gradient, both the rate and degree of water absorption are greatly increased. From data presented, it was calculated that over 90 percent of the total water absorbed by a linseed oil-type paint coating under the influence of both a concentration and a potential gradient was transferred into the film by electroendosmotic forces. Experiments with synthetic resin paints are expected to show significantly lower ratios of electroendosmotic to osmotic effects. Measurements of the flow of electrical current accompanying this phenomenon suggests the possibility that some paint coatings owe their greater resistance to water absorption and blistering not so much to a greater inherent waterproofness as to an appreciably higher electrolytic resistance. Since these tests were conducted with the same vehicle but with four different pigments, it seems reasonable to conclude that the phenomena described are functions of the properties of the pigments employed.

## COATINGS

**Baked-On Plastic Coatings Prevent Corrosion.** E. H. SHORT, JR., Oil and Gas J., **45**, No. 14, 88-90 (1946) Aug. 10.

Thermosetting plastic coatings, oven baked to tubular goods and other types of oil-field equipment, have now been operating in highly corrosive areas for a sufficient period of time to permit an evaluation of performance. Operators who have had plastic-coated equipment in operation long enough to draw comparisons between its service and the material previously in operation, reported excellent performance of plastic-coated equipment in preventing corrosion. The ability of plastic-coated lead lines to resist deposition of paraffin has also been very satisfactory. Method of application is described.—G.P.C.

**Tin Undercoat Improves Corrosion-Resistance of Painted Steel.** E. S. HEDGES and L. A. JORDAN, Paint Manufacture, **16**, 257-258 (1946) July.

Tin coatings as thin as 0.000008 inch were effective in preventing rust on steel exposed to indoor atmosphere during experiments on the electrode-position of tin on steel at the Tin Research Institute. Primers and test procedures are described.—B.L.R.

**Action of Antifouling Paints.** BOSTWICK H. KETCHUM, JOHN D. FERRY and ARTHUR E. BURNS, JR., Ind. and Eng. Chem. (Ind. Ed.), **38**, 931-936 (1946) Sept.

Antifouling paint containing rosin or other acidic resins in the matrix loses both toxic and matrix simultaneously when immersed in the



sea. The loss of matrix is shown to be the result of the dissolution of acidic resin in the slightly alkaline sea water. Theoretical description of the simultaneous dissolution of toxic and matrix is presented and effects of surface residues of insoluble matrix components on the dissolution of the paint are discussed. Toxicity of the paint depends on the loading of the toxic ingredient and the solution rate of the matrix. Independent adjustment of these two variables permit great flexibility in designing a paint with the desired leaching rate.—B.L.R.

## CORROSION TESTING

**Application of Colorimetry to the Analysis of Corrosion-Resistant Steels. Photometric Determination of Copper.** O. I. MILNER, U. S. Navy Yard, Ind. & Eng. Chem., Anal. Ed., **18**, 94-96 (1946) Feb.

A rapid procedure, applicable to low-alloy and corrosion-resistant steels is given with data supporting the validity of the method. From one to three hours are required for corrosion-resistant steels. Copper is first precipitated as sulfide with thio-sulfate, then this is decomposed with a mixture of nitric and perchloric acids.

**Corrosion of Aluminum Pipes.** H. LAFUMA, Inst. Tech. Batiment. Trav. Publ., Circ. Ser. G., **1943**, No. 6, 12 pp.; Chem. Zentr., **115**, No. II, 160 (1944); J. Inst. of Met. & Metall. Abs., **13**, 82 (1946) Mar.

Tensile strength and final elongation of tubes of pure aluminum and aluminum alloys were determined after they had been embedded in

Portland cement, slag cement, gypsum, and lime mortar and exposed to dry and moist air or water. The results are described of corrosion tests in distilled and tap water, 0.1 percent solution of sodium chloride, 0.05 percent solution of calcium sulfate and a very dilute solution of sodium hypochlorite. Conclusions are drawn regarding the applicability of aluminum pipes for water and city gas.

**Comprehensive Laboratory Testing of Instrument Lubricants.** G. E. BARKER, G. E. ALTER, JR., C. E. McKNIGHT, J. R. McKLVEEN AND D. M. HOOD, ASTM Bull., No. 139, 25-35 (1946) Mar.

Report from three years' comprehensive research in new lubricants for fine instruments carried on at Mellon Institute by Instruments Branch, Bureau of Aeronautics of the Navy Dept. Tests for viscosity, cloud and pour points, oxidation stability and corrosion of brass, corrosion and rusting of steel, evaporation, spreading and coefficient of friction of steel on sapphire, lubricated, are described. Evaluation of ability of lubricants to inhibit corrosion of steel is covered. Apparatus and methods described in detail.

**Corrosion Stability of Magnesium Alloys.** J. D. HANAWALT and C. E. NELSON, Light Metals, **8**, 492-505 (1945). J. Inst. Met. & Metall. Abs. **13**, 83 (1946) Mar.

Discrepancies between results of salt-water tests conducted by authors and those reported by Fox and Bushrod (J. Inst. Metals, 1944, p.

325) are explained by the difference in time. Authors' tests lasted from one to four months. Data are given.

**Electrochemical Measurement for Corrosion Studies.** P. T. GILBERT, J. Sci. Instruments, **22**, No. 12, 235-237 (1945); J. Inst. of Met. & Metall. Abs., **13**, 85 (1946) Mar.

A brief description of apparatus used in studying the behavior of pairs of coupled metals in tap-water. The temperature was varied up to 85° C., and concentrations of dissolved oxygen and carbon monoxide were varied. Recorders were devised which enabled a number of quantities to be recorded over long periods. In the combination zinc-iron, the normal behavior in cold water is for zinc to behave as the anode and iron as the cathode. Under some conditions in hot water, zinc becomes much more noble, while the iron may become somewhat less noble. It is then possible for the iron to behave as the anode, and corrosion is accelerated at points where the iron is exposed.

**Salt-Spray Equipment Recommendations.** H. FAIGEN and others. Nat. Paint Bull., **9**, No. 5, 8 (1945); J. Inst. of Met. and Metall. Abs., **13**, 86 (1946) Mar.

Seven important factors are listed in connection with the new salt spray boxes which an ordnance factory might contemplate purchasing or rebuilding. The box should be heated by a hot-water jacket, with the control thermostat located in the water jacket proper, rather than inside the spray box.

**Corrosion Studies on Electrolytic Chromium.** N. HACKERMAN and D. I. MARSHALL, Univer. of Texas Paper Before 89th Gen. Mtg., April 11-13, 1946, Birmingham, Ala.; Electrochem. Soc. Preprint **89**, 15, 171-180 (1946) Apr.

Electrolytic chromium, stripped from its basis metal, was immersed in aqueous solutions of sodium hydroxide, hydrochloric acid, sulfuric acid, acetic acid and sodium chloride at various concentrations, with the last being studied over a pH range from 0 to 11. The metal was used in both the active and passive states and the solutions, saturated either with air, nitrogen, or hydrogen, were maintained at 35° C. Results are reported.

## FUNDAMENTALS

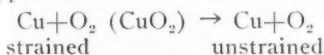
**Overvoltage and Its Significance In Corrosion.** SAMUEL GLASSTONE, Corr. & Mat. Prot. **3**, 15-18 (1946) June-July.

Shows that in certain cases overvoltage can play an important part in corrosion phenomena involving a single metal or two different metals (or a metal and a conducting impurity) in contact. A metal of low overvoltage can increase corrosion, whereas a high overvoltage metal may be used to inhibit the corrosion of a base metal.—B.L.R.

**Initial Stages of the Reaction Between Copper and Oxygen.** D. H. BANGHAM, J. Sci. Instruments, **22**, No. 12, 230-231 (1945); J. Inst. of Met. & Metall. Abs., **13**, 82 (1946) Mar.

Experiments made by V. Bloomer in 1935-36 are described and discussed. The reaction between cop-

per-foil and oxygen was studied, with special reference to the effects at temperatures and pressures sufficiently low for the usual parabolic time law not to be valid. Under these conditions there was an initial period during which no oxygen was taken up by the copper; some inhibitor may have been present which had to be destroyed before the reaction began. The rate of absorption of oxygen then increased, and then gradually diminished to a very small value. One specimen of unannealed (i.e., cold-worked) copper-foil showed an unstable behavior, in which the oxygen pressure in the chamber alternately rose and fell. B. suggests a reversible absorption of oxygen by copper.



A similar process may account for the behavior of thin silver mirrors observed by Liepus.

#### FUNDAMENTALS

**Daniell Galvanic Circuits in Fused Bromides.** YU. K. DELIMARSKII, J. Phys. Chem., U.S.S.R., **19**, 465-468 (1945); Record of Chem. Progress, **7**, No. 1-2, 58 (1946) Jan.-Apr.

Since an electrolyte containing ions in common with the cations of a glass diaphragm immersed in it has practically no potential difference between the two phases on the two sides of the diaphragm, the author established the series of electrode potentials of the metals by measuring the corresponding Daniell circuit. He dissolved the bromide to be studied in a fused mixture of aluminum bromide and sodium bromide. Aluminum, manganese, zinc, cadmium, lead, tin and copper

became negatively charged in the Daniell cell formed; while iron, mercury, nickel, cobalt, antimony and bismuth became positively charged with respect to a sheet of silver immersed in a melt containing silver bromide used as a reference electrode. Metals were arranged in an electrolytic potential series as follows: aluminum, manganese, zinc, cadmium, lead, tin, copper, iron, mercury, cobalt, antimony, and bismuth. This is the same order found by investigating the metal-salt equilibrium.

#### GAS AND CONDENSATE CORROSION

**Corrosion Studies in Natural Gas Condensate Wells. Protective Layers.** D. A. SHOCK AND N. HACKERMAN, A.C.S. 110th Mtg. Chicago, Sept. 9-13, 1946. Abstr. of Paper: 401.

A mechanism has been proposed to explain the absence of differential attack and the low rate of general attack in a certain type of natural gas condensate well. This postulates the presence of a naturally occurring inhibitor in the hydrocarbon phase which reacts with the steel surface to form a thin but highly protective layer. An investigation, made of the hydrocarbon phase, particularly from the point of view of its acidity, disclosed the presence of some constituent which was not found in the hydrocarbon phase of a corrosive well. The choice of an inhibitor for injection into a corrosive well is discussed on the basis of this mechanism and the information obtained on the hydrocarbon phase. Naphthenic acid was found to meet the requirements of such an inhibitor and its use and effect-

tiveness are discussed. In addition, the type of protection provided by sodium dichromate under the reducing conditions such as are found in these wells is also treated. Both of these inhibitors react with the steel surface, but the products formed provide protection. However, it seems that the naphthenic acid offers less chance of subsequent dangerous attack.

**Summary of the Investigation of Drill-Pipe Failures in the Permian Basin.** L. R. JACKSON, H. M. BANTA AND R. C. McMASTER, *Oil and Gas J.*, **45**, 75 (1946) Aug. 31; *Drilling*, **7**, 30 (1946) Sept.

Discusses suitable methods for preventing failures: use of inhibitor in drilling muds, protective coatings on inside of pipe and keeping pipe in tension to prevent bending stresses that lead to fatigue failures. —B.L.R.

**Summary of the Investigation of Drill-Pipe Failure.** R. L. JACKSON, H. M. BANTA AND R. C. McMASTER, *Drilling*, **7**, No. 11, 30 (1946) Sept.

The short service life of pipe in the Permian Basin fields revealed the cause to be corrosion due to salt water. Remedies suggested are the use of chromate inhibitor in the drilling fluid, protective coating on the casing and/or use of separate string of pipe for drilling only the salt section.

## GAS AND CONDENSATE CORROSION

**Formation and Nature of Surface Layers on Steel in High-Pressure Natural Gas Condensate Wells.** N. HACKERMAN AND D. A. SHOCK, A.C.S. 110th Mtg. Chicago (Sept. 9-

13, 1946); *Abstr. of Papers*: 39-401.

Corrosion in high-pressure natural gas condensate wells caused by  $\text{CO}_2$  and lower fatty acids has become a serious operation problem to the natural gasoline industry. A method of exposing and studying a series of coupons in the well head was devised. Micrographic study of coupons so exposed has led to a means of classification and prediction of the corrosive character of these high-pressure condensate gas wells. The photomicrographs show different types of surface layers formed by a corrosive, a non-corrosive, and an intermediate type of well. Weight loss curves further substantiate the difference in the surface layers as shown by the photomicrographs. The extent and character of the corrosive attack depend on the type of layer formed. These layers are compared with some formed on steel in a laboratory apparatus under controlled exposure conditions. From the comparison of laboratory coupons and the coupons from the wells, it is indicated that a natural inhibitor, such as the naphthenic acids, is present in the liquid hydrocarbon phase and is the reason that some of the wells are non-corrosive.

## Sodium Chromate as a Corrosion Inhibitor in Gas-Condensate Wells.

Part 1. C. K. EILERTS, H. A. CARLSON, R. V. SMITH, F. G. ARCHER AND V. L. BARR, Paper presented before NGAA Annual Mtg. Apr. 4, 1946, *Oil Wkly.*, 30-9-46, **123**, 17 (1946) Sept. 30.

Laboratory tests on the inhibitory properties of sodium chromate against corrosion of steel by aqueous solutions of carbon dioxide, fatty

acids and phenols lead to tests on a well. The apparatus and technique are described in detail. The tests in the Opelika field lasted approximately 60 days and showed that when two or three pounds of sodium chromate in solution is injected into the entrance of the tubing with each million cubic feet of gas produced, rates of corrosion of coupons and the amounts of iron in the effluent water are reduced to negligible values. It was not possible, however, to substantiate these evidences of the corrosion-inhibiting value of sodium chromate by inspection of the well equipment before and after the tests. The treatment with sodium chromate was accompanied by gradual formation of an obstruction in the tubing. The deposit that formed the obstruction was readily soluble in hydrochloric acid used to clean the well, but it probably was not a water-insoluble calcium or magnesium salt—less than 10 ppm. of these elements were present in the water from the formation. The relation between flow rate and casinghead pressures did not change at any time during the test, and there was no indication that casing perforations were obstructed. It was evident throughout the tests that more water was needed to maintain a return of sodium chromate in the effluent water from the well than the minimum required to dissolve the sodium chromate injected.

## INHIBITORS

**Polarization Studies of Inhibitor Action.** R. D. MISCH AND H. J. McDONALD, ACS 110th Mtg., Chicago, Sept. 9-13, 1946, Abs. of Papers: 17-18p.

Polarization behavior of corrosion inhibitors was studied with a modified polarization cell, originally developed by J. M. Bialosky, Armour Res. Found. The cell consists of two parts, which hold the solution and are clamped on opposite sides of a metal specimen. A current is passed through the system; one metal face becomes anodic and the other cathodic. The potential at these surfaces is measured for different current densities. Polarization curves are obtained by plotting these values against current density. The influence of inhibitor structure is shown in characteristic curves. A regular change in polarization characteristics is found for a homologous series. The experimental differences in behavior of anodic and cathodic inhibitors is shown. The importance of the metal specimen is shown for steel of different analyses. A correlation was found between the polarization curves and stress corrosion susceptibility of various steels. Besides the use of various inhibitors, metals, and ions, the influence of pH, temperature, and solution velocity was studied. The depolarizing action of various ions on inhibitors is shown. A comparison of the effectiveness of some common inorganic and organic inhibitors at various concentrations is also made. The value of the polarization cell in evaluating inhibitors is discussed.

**Rust Preventive Oils.** G. D. PILZ AND F. F. FARLEY, Ind. Eng. Chem. **38**, 601-609 (1946).

Rust preventive oils, composed of polar organic compounds in mineral oil, have been employed extensively in film applications for the tempo-

rary protection against rusting of iron and steel parts during manufacturing operations, storage, shipment and use. The condensation of moisture in droplets on such oil-coated steel parts produces a dynamic system composed of water, oil film, and metal. A study of the contact angles formed by such a system where a drop of water rests on a horizontal oil-coated steel panel, has established a relationship between contact angles and rust preventive ability. A mathematical analysis of the forces involved in the spreading of a water drop on a rust preventive oil film has shown that the equilibrium surface tensions of the water and oil, and their interfacial tension are the major factors determining the magnitude of the contact angle. These findings are in agreement with the theory of rust prevention which postulates orientation of the polar additive at the oil-metal interface and establishment thereby of a barrier to normal mode of entry of the rusting agents—oxygen and water.

Contact angles were measured by a microscope fitted with a goniometer eyepiece; they have been employed in determining that solubility in water is of prime importance among the physical properties of rust preventive additives and have found application in controlling plant production of rust preventive oils.

**Review of Inhibitors.** WALLACE G. IMHOFF, Wire and Wire Products, 21, 598-599, 621-623 (1946) Aug.

U. S. inhibitor patents.—B.L.R.

## INSPECTION

**Fluoroscopy.** B. CASSEN AND D. S. CLARK, Metal Industry, 69, 25-27 (1946) July 12.

Discusses its application to the examination of metallic objects.—B.L.R.

**Supersonic Waves for Detecting Cracks in Steel.** C. H. DESCH, D. O. SPROULE, and W. J. DAWSON, Welding, 14, 321-328 (1946) July.

With equipment shown it appears that the varying hardness and microstructure of the thermally disturbed zone of the parent plate, and also the structure and analysis of the weld metal, do not cause any appreciable damping or reflection of the supersonic beam. Great advantage of the supersonic method of testing is that very thick welds are well within its scope, and it should thus be possible to reveal flaws which the radiographic method might not detect.—B.L.R.

**Supersonic Method for the Detection of Internal Flaws.** E. G. STANFORD and H. W. TAYLOR, Metallurgia, 34, 59-66 (1946) June.

Examination of the method as applied to aluminum alloy billets and semi-finished components. Remarkably good results have been obtained on rectangular sections and cylindrical bar, but extruded sections of complicated shape are difficult to deal with. Scheme is outlined whereby the apparatus may be assembled for routine testing under production conditions.—B.L.R.



**Internal Tubing Caliper.** P. E. CHANEY, Sun Oil Company, Paper before Natural Gasoline Assn. of Am., Dallas, April 17-19, 1946, *Pet. Eng.*, **17**, No. 7, 122, 124 (1946) Apr.

Design, mechanism, and operation of the Chaney-Barnes tubing caliper, used to measure internal corrosion in tubing and well head fittings of gas-condensate wells, are described and illustrated. Caliper is accomplished by means of six or more independently operating lever arms, to the outer ends of which are attached small wheels or rollers to contact the tubing wall. Each lever arm is provided with a spring to urge the feeler wheel outwardly against the tubing wall. Inner arms of the levers contact a polishing steel plate on the end of the stylus rod.

**Contribution to the Micrographic Examination of Copper. Revealing of Inclusion, Cold-Hardening, Recrystallization and Microfissures.** M. P. JACQUET, *Revue de Metallurgie*, **42**, No. 5, 133-148 (1945) May (In French).

The combined use of electrolytic polishing and some new methods of attack by means of hydrogen sulphide reagent or by putting electrodes into short circuit after polishing allows one, not only to improve the quality of micrographs of copper, but also to reveal some structural details completely invisible if one uses mechanical polishing and customary attacks. The technique described gives excellent results for the observation of traces of inclusions in pure copper and the beginning of recrystallization of the cold-hardened metal. The new results

concern: 1) structural modifications provoked by the mechanical work; 2) detection of an intermediate stage between the structures cold-hardened and recrystallized, that only radiocrystallography was able to show until now. A copper 99.75 percent pure containing 0.02 percent nickel is mentioned in a discussion of the detection of microfissures. Some observations relative to a copper-manganese-nickel alloy and a diagram of the cold-hardening of a copper-manganese-nickel crystal are given. Micrographs are shown. Nineteen ref.

## METAL FAILURE

**Martensite Transformation.** A. R. TROIANO AND A. B. GRENINGER, *Metal Progress*, **50**, 303-307 (1946) Aug.

Describes the known salient characteristics of the martensite transformation and shows how it differs basically from the process of transformation by nucleation and growth. —B.L.R.

**Shot Peening.** *Western Machinery & Steel World*, **37**, 100-102 (1946) July.

Chart shows increase in fatigue life due to shot peening of certain parts. 18 ref. —B.L.R.

**Atomic Physics and the Strength of Metals.** N. F. MOTT, *Metal Treatment*, **13**, 119-126 (1946) Summer.

Account of main contributions of wave mechanics to the physics of metals, stressing limitations of theory. Illustrates the methods of theoretical physics by a theory of oxidation of metals, and by some remarks

about the dislocation theory of slip. Some new points about the dislocation theory of slip are brought forward. Eighteen ref.—B.L.R.

**Graphitization in Some Cast Steels.** A. J. SMITH, JOHN URBAN, AND J. W. BOLTON, *Welding* **25**, 257s-268s (1946) May.

From many samples studied both from field service and controlled laboratory experiment, it has not been shown possible to insure against graphitization of carbon molybdenum steel through controlled procedures of melting and deoxidation practice or heat treatment. A hypothesis has been put forth concerning the mode of graphitization based on the observed graphitization behavior of both plain-carbon and carbon-moly steels. Use has been made of this hypothesis to explain the resistance to graphitization of the nickel-chrome-moly steels. The experimental evidence would appear to indicate that the hypothesis is substantially correct. Fourteen ref.—B.L.R.

**Importance of Ultimate Extension as an Engineering Property of Materials.** A. FISHER, *Metallurgia*, **34**, 77-84 (1946) June.

Shows that a condition of specific strain is far more common in engineering structures than is generally supposed; that under condition of specific strain it is quite useless to put in material with a higher modulus of elasticity, higher proof strength or higher anything which moves stress-strain curve to the left, in the hope that higher strength will result, because such a move merely results in a higher stress being gen-

erated; that under conditions of specific strain a component fractures if its available percentage extension is below that required under the imposed strain, irrespective of its strength; that percentage ultimate extension is a valuable property in any material to be used where stress concentrations exist; that higher percentage extension may mean greater safety in the event of abnormal loads, and not necessarily greater weight.—B.L.R.

**Low-Temperature Behavior of Ferritic Steels.** H. W. GILLET AND FRANCIS T. MCGUIRE, *Steel*, **119**, 76+ (1946) Aug. 12.

Comprehensive data secured from experimental work carried out as a War Metallurgy Committee project correlates and clarifies some points of low temperature behavior of commercial NE, SAE, and similar steels relating to composition, heat treatment, grain size, hardenability, etc., and also corroborates conclusions obtained in earlier investigations of similar nature.—B.L.R.

**Some Observations on the Effect of Oxygen on Carbon in Steel.** LESLIE FINE AND CHARLES H. MAAK, *Welding*, **25**, 283s-287s (1946) May.

A drop in hardness occurs in the weld plane of aswelded oxyacetylene pressure welds made of low alloy medium carbon steels under deliberately poor welding conditions. The alkaline chromate etch has shown evidence of considerable dissolved oxygen in such welds. With this in mind, further investigation of the effect of oxygen upon the behavior of carbon in steel was carried on and evidence presented.—B.L.R.

**Corrosion of Metals. Part IV. Corrosion of Iron and Steel.** Sheet Metal Industries, **23**, 1333-1342 (1946) July.

Deals with effects of coupling iron with other metals, intergranular attack of iron and its alloys, intergranular attack of improperly heat-treated stainless steel, corrosion-fatigue properties of various iron alloys, corrosion of stainless steel.—B.L.R.

**Behavior of 18-8 Titanium-Stabilized Stainless.** ERNEST H. WYCHE, Iron Age, **158**, 61-65 (1946) Aug. 8.

Various means of detecting and combating intergranular corrosion in 18-8 stainless steel are discussed. Effects of the stabilizing elements, titanium and columbium, on the physical properties of wrought 18-8 stainless steels are also considered, together with precautions to be observed in calculating proper ratios of these elements for best results. Twenty-two ref.—B.L.R.

**Influence of Heat Treatment Upon the Susceptibility to Graphitization of High Aluminum Deoxidized Carbon-Molybdenum Steel.** F. EBERLE, Welding J., **25**, 307s-312s (1946) May.

Describes a series of experiments carried out to explore the influence.—B.L.R.

**Corrosion Resistant Aluminum Alloy.** Corr. & Mat. Prot., **2**, No. 9, 29 (1945) Dec.

A new light-weight aluminum alloy, OH38, has a Brinell hardness of 95 to 98, excellent wearing qualities, was found to lose no tensile strength

after 10 days exposure in salt water immersion tests, is more resistant to lactic acid than Dairy Metal (often called "nickel silver"), and resisted corrosion from various lubricants and coolants. Composition is not given. Coefficient of expansion is 0.000015. It is very machinable. First used to replace malleable iron for a main body-casting for a portable tool used to wire-tie steel products before placing on railroad cars, it is now used in an unlimited number of applications. Use as bearing metal is mentioned.

**Test for Hydrogen Embrittlement and Its Application to 17 Percent Chromium, 1 Percent Carbon Stainless Steel Wire—TP1954.** C. A. ZAPFFE AND M. HASLEM, Paper before AIME, Cleveland Meet., Oct., 1944; Metal Tech., **13**, No. 1, 1-28 (1946) Jan.

An apparatus for measuring hydrogen embrittlement of stainless steel wire is described. An approximate indication of sensitivity of various stainless grades of steel, including 16-2, to hydrogen embrittlement was obtained, and certain factors controlling the absorption of hydrogen during cathodic and acid pickling and the desorption of that gas during subsequent recovery were studied. Many of the reagents called "inhibitors" actually cause a marked increase in embrittlement over that of the raw acid for the conditions of these tests. The peculiarities of a group of these reagents are studied in detail. The significance of the tests in disclosing the nature of hydrogen in steel serves to prove the planar-pressure theory for hydrogen

embrittlement and voids the concept of embrittlement as a function of compound formation or lattice distortion. Graphs show embrittlement as a function of charging time, temperature, current density, comparison of effect of acid and alkaline electrolytes, temperatures. Relation of hydrogen embrittlement to electrical resistivity is also tabulated and discussed.

**Effect of Composition and Environment on Corrosion of Iron and Steel.** C. P. LARRABEE, Carnegie-Illinois Steel Corp., Paper before ASM, Ann. Mtg., Cleveland, Feb. 4-9, 1946; *Marine Eng. & Shipping Rev.*, **51**, No. 2, 134-135 (1946) Feb.

The effect of each alloying element is not quantitatively the same at marine and industrial locations. Data accumulated on commercial products under atmospheric corrosion tests show, among other things, that there is an appreciable superiority for chromium-silicon-copper-phosphorus steels over nickel-copper-molybdenum-phosphorus steels in the industrial atmosphere of Kearny, N. J., and that these steels had lower losses than the second group at the semi-rural atmosphere at South Bend, Pa. There was no significant difference in the corrosion losses between several steels containing nickel and copper, with or without additions of other alloying elements. The copper content is the controlling factor in corrosion rates of low metalloid open hearth irons and steels. Average penetration is about 0.004 inch per year. Corrosion is very severe between tide levels and particularly above high

tide level, where steels are wet periodically or only occasionally by salt water.

**Behavior of Nickel-Copper Alloys in Sea Water.** H. H. UHLIG, Gen. Elec. Co., *Record of Chem. Progress*, **7**, No. 1-2, 56-58 (1946) Jan.-Apr.

Corrosion resistance and reaction to biological activity in sea water of nickel and copper separately and of various compositions of nickel-copper alloys are discussed. The passive state is retained only up to a copper concentration of 60 percent. Alloys below 40 percent nickel are active and release sufficient copper ions in sea water to discourage fouling. Above 40 percent, nickel alloys are passive.

**Cavitation and Its Effect on Turbines and Pumps.** S. L. KERR, Paper before ASME, Hydraulic Sec., Phila. April, 1946; ASME, 1946, Preprint (Mimeo.) 7 pp.

Occurrence of and remedies for cavitation in turbines and pumps are discussed. Tests discussed include Venturi, jet and vibratory. A table gives relative resistance of 15 metals, including nickel-copper alloy, chromium-nickel steel alloy steel, and iron and cast steel and iron to cavitation erosion (relative results from Kerr's vibratory tests, *Trans. ASME*, July, 1937, 373-397).

**Effect of Stabilizing and Stress Relief Heat Treatment Upon Welded 18-8 Stainless Steel.** W. G. HUBBELL, Ryan Aeron. Co., *Steel Processing*, **32**, No. 3, 181-186 (1946) Mar.

From investigations on the effect

of stabilizing and stress relief heat treatment of welded 18-8 stainless, it was concluded that heating welded sections of 18-8 types 321 and 347 stainless for 30 minutes at 1650° F. exerts some small, but inconclusively beneficial results in one respect of minor significance to resist attack by corrosive aqueous solutions and electrolytes. There appears to be no justification for assuming that any substantial and practical benefit will be obtained by applying this type of heat treatment to aircraft exhaust manifolds. Tests included exposure of columbium and titanium stabilized material to the Strauss test in copper-sulfate-sulfuric acid solution for 48 hours, and microscopic examination. Bend tests were also administered. Manufacturing problems increased by heat treatment at 1600° F. include formation of a very tight, thin scale difficult to remove. Service reports from the Ryan laboratory indicate minor types of failure of manifolds are due: 1) to fatigue occurring in open areas subjected to strong pulsating forces and 2) to presence of severe stress raisers in the critical areas. Both are rectified by redesign. Photomicrographs include a picture of a weld zone taken from an exhaust manifold in continuous service from 1938 to 1944, which shows that the life of a manifold is not related to condition of dispersal of carbides, since a heavy network of carbides was revealed.

**Alloys Beat the Heat.** E. P. PETERS, *Scientific American*, **174**, No. 152-154 (1946) Apr.

The 1500° F. temperatures now considered maximum for gas tur-

bines may eventually be regarded as old-fashioned and inefficient. Materials and production methods used in the new jet-propelled engines and gas turbines are discussed in a readable but concretely scientific vein. The two types of materials emerging as fundamentally suited to ultra-high temperature service are: austenitic or ferritic stainless steels containing nickel and chromium up to 45 percent, to which molybdenum, titanium and tungsten are added separately or in combination; and columbium or nickel-base alloys containing chromium and tungsten, molybdenum, nickel or columbian as major alloying elements. The two major problems of load-bearing strength and dimensional stability at high temperatures are not simultaneously solved with any one alloy. The modified stainless steels have excellent strength at high temperatures, but are not ideally stable dimensionally, whereas the columbian-base alloys are precise but not the strongest members of the team. The newest high-temperature material made public to date, is the 16 percent chromium, 25 percent nickel, 6 percent molybdenum steel developed by Timken Roller Bearing Co. Over 12 million pounds of this alloy were used in the past four years. The 16-25-6 alloy is  $2\frac{1}{2}$  to 3 times as strong as 18-8 stainless at 1500° F. The Elliott Lysholm gas turbine is shown with materials and parts.

**Stress-Rupture Characteristics of Various Steels in Steam at 1200° F.**

J. T. AGNEW, G. A. HAWKINS AND H. L. SOLBERG, *Purdue Univ., Trans., ASME*, **68**, No. 4, 309-315 (1946) May.

Small tensile specimens made from low - carbon, carbon - molybdenum,  $2\frac{1}{4}$  percent chromium-1 percent molybdenum, 5 percent chromium-molybdenum-silicon, 9 percent chromium-molybdenum-silicon, 12 percent chromium, 18 percent chromium-8 percent nickel, 25 percent chromium-20 percent nickel, and 5 percent chromium-molybdenum-titanium steels were placed in a steam reaction chamber at 1200° F. and stressed in tension for periods of time ranging from 10 hours to 7700 hours. Data were taken on time as to rupture, elongation, reduction in area, depth of scale layer, effect of type of flow, and type and angle of fracture. A photomicrographic study was made of the ruptured specimens. The straight-line relationship between stress and time to rupture on log-log coordinates postulated by White, Clark, and Wilson for tests in air also holds for tests in steam. Steels of 25 percent chromium-20 percent nickel, and 18 percent chromium-8 percent nickel were characterized by very brittle fractions for both the long and short-time intervals, resulting in low values for reduction in area and elongation. The values for elongation for the fractured specimens of 18 percent chromium-8 percent nickel ranged from 8 to 51 percent, while those for 25 percent chromium-20 percent nickel were a little higher, ranging from 32 to 75 percent. For all of the nine alloys taken as a whole, no satisfactory correlation between time to rupture and either elongation or reduction in area could be obtained. An examination of the microstructure of all the alloys revealed no clearly defined graphite in any case.

**Before Specifying Magnesium, Study Processing Techniques.** N. H. SIMPSON, Consolidated Vultee Aircraft Corp., Electrical Manufacturing, **37**, No. 4, 135-137+ (1946) April.

Material on corrosion resistance of magnesium alloys, with specimens from spray tests, discussion on stress corrosion and tolerance limits for iron, nickel and copper in magnesium, and magnesium alloys are discussed and shown. Results of test to show effect of cleaning on corrosion resistance of magnesium in salt-spray tests are illustrated. Scattered pitting, which indicated improper heat treatment or cathodic particles of metal forced into the surface, is also shown. A table gives potential differences of dissimilar alloy couples in sodium chloride, including 18-8, 1025 and magnesium alloys.

**Corrosion Resistance of Stainless Steels.** J. M. MARGOLIN, C. M. SACHNOVITCH AND P. I. JUSVINSKAYA, Iron Age, **157**, No. 21, 50-55 (1946) May 23.

Results of decarburization tests on high carbon-13 percent chromium steels conducted by Russian investigators in order 1) to remove carbon from surface layers to obtain good corrosion resistance and 2) retain carbon in core to preserve strength are reported in text, tables and graphs. In the United States, these properties are normally obtained by increasing nickel content. The Russians found magnesium carbonate the best chemically active solid decarburizing agent. Temperature and duration of decarburization process and microstructure and effect on



strength of steels are discussed and shown. Results of tests in 10 percent nitric acid are given.

**Transformation of Austenite in Carbon Steels of the Pearlite Type.** R. MITSCHKE AND A. LEGAT, *Berg und Huttenmannische Monatshefte*, **90**, No. 4, 43-47 (1942).

Austenite decomposition of carbon steels in pearlitic state is explained with special reference to effect of endogenous nuclei (e.g. undissolved residual cementite) and exogenous nuclei (e.g. submicroscopic nonmetals). Resultant decomposition structures are classified as 1) lamellar high or low-temperature pearlite and 2) spheroidal cementite shapes originated either by direct austenite decomposition or by spheroidization of lamellar structures. Influence of annealing time upon solution processes of nuclei and on mode of austenite decomposition was studied in two series of experiments. Steels used were: 0.86 percent carbon, 0.31 percent manganese, 0.19 percent silicon, melted in basic electric furnace and deoxidized without aluminum or other special deoxidizers, and 0.78 percent carbon, 0.35 percent manganese, 0.18 percent silicon, melted in basic electric furnace in conventional way, or treated with aluminum and silicon for deoxidation, respectively.

**Seven Years' Operating Experience at Bonneville Hydroelectric Plant, Power**, **90**, No. 3, 64-68 (1946) March.

Pitting in turbine blade-runners adjacent to stainless steel insert deposited on underside of blades by arc-welding process is described. Turbine pitting repair by stainless

steel welding is carried out every two years, and preparation for the welding is considered as important as welding and finishing of blade surfaces. Welding rods of shielded-arc 18-8 stainless steel were used. A diagram of the cast-steel runner with stainless steel insert is shown, together with area over which pitting occurs.

**Some Practical Instances of Corrosion of Nonferrous Metals in Telecommunications Apparatus.** W. G. RADLEY, *J. Sci. Instruments*, **22**, 237-238 (1945); *Chem. Abs.*, **40**, 1773-1774 (1946) April 10.

In any underground cable system when stray currents are present, their measurement is an important step in planning remedial measures. Local stresses and differential aeration may be set up on the surface of the conductors by the lapping, and copper may be exposed through pinholes in tin coating. Under damp conditions, these factors are likely to lead to corrosion by electrolytic couples. Electrolytes, which are inevitably present in textiles to a greater or less extent, will make such local action more severe. A potential difference sometimes exists between two touching wires; also the effect of humidity is of importance. Wax impregnation acts merely as a resistance which delays the establishment of equilibrium between the textiles concerned and the external humidity.

**Influence of Heat-Treatment Upon the Susceptibility of High-Aluminum-Deoxidized Carbon-Molybdenum Steel.** F. EBERLE, Trans., ASME, **68**, 625-630 (1946) Aug.

Susceptibility to graphitization of carbon-molybdenum steels may be influenced by heat-treatment prior to installation. Tests are reported in this paper on high-aluminum-deoxidized pipe with welded upset ends, the upsetting being carried out at 2000° F. without subsequent heat treatment. Graphitization in certain zones of the pipe were in evidence. Subsequently the influence of prior heat treatment or weld heat effects upon susceptibility to graphitization was explored. The procedure and results attained are recorded in this paper.—G.P.C.

**Comparative Graphitization of Some Low-Carbon Steels with and without Molybdenum and Chromium.** G. V. SMITH, S. H. BRAMBIR AND W. G. BENZ, Trans., ASME, **68**, 589-595 (1946) Aug.

Study of several experimental heats of steel containing 0.5 percent molybdenum and up to 1.20 percent chromium showed that in steels containing 0.5 percent or more of chromium, no graphitization occurred in 3000 hours at 1025° F.; but this finding requires confirmation by study of additional heats, particularly of commercial manufacture. Additional studies relating to the effect of deoxidation practice, particularly in plain carbon steels, and of the effect of post-treatment of welds on graphitization are described.—G.P.C.

**Further Observation of Graphitization in Aluminum-Killed Carbon-**

**Molybdenum-Steel Steam Piping.** R. W. EMERSON AND M. MORROW, Trans., ASME, **68**, 597-607 (1946) Aug.

Among graphitization of steel pipe studies being carried on, the present one deals with what the authors have termed "slip-plane" graphitization, which describes a condition of graphite segregation along slip planes where local "yielding" or localized plastic deformation had previously occurred. Such graphitization has been found to vary widely from the outside to inside of a pipe and from quadrant to quadrant around the pipe periphery. It has been determined that "nodular" graphite segregation whether of the "isotherm" or slip-plane type is as effective as "chain" graphite in reducing the ductility of low-carbon or low carbon-molybdenum steel.—G.P.C.

**Studies on Susceptibility of Casting Steels to Graphitization.** J. J. KANTER, Trans., ASME, **68**, 581-587 (1946) Aug.

This is a progress report for project No. 29 of the Joint ASTM-ASME Committee on Effect of Temperature on the Properties of Metals. One of the activities undertaken by project No. 29 has been the study of certain aspects of the graphitization problem applying to the carbon-molybdenum casting steels used in welded piping structures. The steels so involved are of the types covered in ASTM Specifications A217 covering Pressure Alloy Castings Suitable for Fusion Welding such as valves, flanges, fittings, and other

pressure-containing parts for high-temperature services. This investigation was undertaken in cooperation with the Manufacturers Standardization Society (MSS) of the Valve and Fitting Industry, through a committee representing the constituent manufacturers engaged in the founding and manufacture of steel valves, flanges, and fittings.—G.P.C.

**Problem of Fracture. Failure of Welded Steel Structures and Recommended Research.** JOHN H. HOLLOMON, *Welding J.*, **25**, 534s-583s (1946) Sept.

Attempts to interpret knowledge of fracture in terms of consistent theory. Where there are divergencies in knowledge, and where theory is adequate, an attempt is made to indicate the direction of research to resolve the difficulty. Coordinates approaches of the mechanical engineer, the metallurgist, and the physicist, and welds the knowledge gained from them. 126 ref.—B.L.R.

**Notch Sensitivity in High-Strength Aluminum Alloys. Theoretical Aspects.** L. SCHAPIRO AND H. E. NORTH, *J. of the Aeronautical Sciences*, **13**, 391-395 (1946) Aug.

Study of the effect of various types of notches and notched depths on static ultimate tensile strength of 14ST, 75ST and 24ST aluminum alloys. An ideal stress notch insensitive material is defined in terms of a logarithmic relationship between notched ultimate stress and notch depth. Test data indicate that the logarithmic relationship is a good first approximation and that a scale

of stress notch sensitivity may be established.—B.L.R.

**Effect of Notches Upon Limiting Strain in High-Strength Aluminum Alloys.** O. A. WHEELON AND ST. J. BARRETT, *J. of the Aeronautical Sciences*, **13**, 401-404 (1946) Aug.

Bending tests were conducted on 1/2-inch square, notched bars of 14ST, 24ST, and 75ST. It was found that notches of any depth drastically reduce the limiting strain for all materials tested and for all testing temperatures. Data presented graphically.—B.L.R.

**Summary Report on the Joint EEI-AEIC Investigation of Graphitization of Piping.** S. L. HOYT, R. D. WILLIAMS AND A. M. HALL, *Battelle Memorial Institute, Trans.*, ASME, **68**, 571-580 (1946) Aug.

Following the failure in January, 1943, of a welded joint in a high-pressure steam line at the Springdale Station of the West Penn Power Co., among the several investigations undertaken, a research program was initiated at Battelle Memorial Institute to study the fundamental causes of graphitization and the restoration of graphitized joints. This paper is a summary of the findings to date on graphitization and includes the work of the Institute and reports by approximately 40 operating companies. It gives the present status of significant points which have emerged in relation to manufacture and fabrication.—G.P.C.

**Intercrystalline Corrosion of Aluminum-Magnesium Alloy Rivets.** G. J. METCALFE, *J. of the Inst. of Metals*, **72**, 487-500 (1946) July.

A number of service failures in aluminum alloy rivets containing 7% and 5% of magnesium are attributed to intercrystalline corrosion. Normally aluminum alloy rivets containing 5% of magnesium are not susceptible to intercrystalline corrosion but when they are subjected to tropical temperatures for long periods precipitation of the B-phase occurs, which renders them susceptible to intercrystalline attack. Cold working is found to facilitate grain-boundary precipitation. Low-temperature stabilizing treatments are unsatisfactory. Corrosion tests show that in rivets that have been previously heated at 70° C. for 14 days intercrystalline corrosion occurs at the junction of the shank and the head.—B.L.R.

**Stabilization of 18% Chromium-8% Nickel Corrosion-Resisting Steel.**

SAMUEL J. ROSENBERG, National Bureau of Standards, Report No. 7, Aug. 23, 1946, 6 pages, 45 tables.

Gives results of the sixth, seventh and eighth phases of test program involving study of susceptibility to intergranular attack of test steels as initially cold rolled (37½ percent cold reduction), followed by different preliminary treatments.—B.L.R.

**REFINERY CORROSION**

**Desalting of Petroleum With Fiberglass Packing.** C. G. KIRKBRIDE, Petroleum Refiner, 25, 95-103 (1946) July.

A pilot plant investigation was carried out at the A. and M. College of Texas to determine the feasibility of using beds of relatively fine glass

fibers for desalting of petroleum. This work was extended by a pilot-plant investigation at the Whiting, Indiana, refinery of Standard Oil Co. (Indiana). The process consists briefly of 1) washing the crude oil with water at a minimum temperature of 250° F., 2) passing the oil and water through beds of glass fibers averaging 0.00028 inches in diameter to coalesce the emulsified water, and 3) separating the desalted oil from the wash water. The wash water may be recycled in most cases to conserve heat and fresh water. Only sufficient fresh water is needed if recycling is done to maintain the salt content of the wash water at a maximum of 3 percent by weight. Life of the Fiberglas packing is in excess of two months. It has been found that salt content can be reduced to less than 10 pounds per 1000 barrels of oil by proper control of temperature, superficial velocity and glass surface in the beds. In general, the temperature should be at least 275° F. for best results. A superficial velocity of 1.0 foot per minute seems feasible for commercial units, provided the temperature is maintained sufficiently high to give a pressure drop of not over 5 pounds per square inch through a single bed of Fiberglas packing. A total of five individually supported beds, each two inches in depth at 6.5 pounds per cubic feet density, appears a reasonable basis for commercial designs to provide to not over 10 pounds per 1000 barrels. The process is effective, and appears to be quite attractive from an economic standpoint for commercial applications.—G.P.C.

## SURFACE TREATMENT

**Preparing Steel Surfaces for Maximum Paint Adhesion.** CHARLES DELMAR TOWNSEND, *Products Finishing*, **10**, 50-52 (1946) Aug. . .

Tests have demonstrated that steel cleaned with cripecoat can be stored for 90 days without indications of rust. Is an acidic material that has wetting, penetrating and emulsifying properties.—B.L.R.

**Phosphating Metallic Surfaces—I, II, and III.** W. G. CASS, *Chemical Age*, **55**, 5-8 (1946) July 6; 35-38 (1946) July 13; 67-70 (1946) July 20.

Essentially a review of literature and patents on the above. Topics covered are: History of phosphating; early patents; preparing the surface; preliminary cleaning; types of bath; factors for efficiency; uses of sulfates; low temperature phosphating; inorganic and organic accelerators; catalysts; quality of coatings; influence of corrosive conditions; oil absorption powers; renewing the bath; phosphating nonferrous metals; special uses; aid to lubrication. (Large number of references given within the papers.)—B.L.R.

**Environmental Control of Metal Cleaning Processes.** F. A. PATTY, *Monthly Review*, **33**, 809-819 (1946) Aug.

Factors to be considered in metal cleaning; classification of cleaning processes.—B.L.R.

**Blast Cleaning Materials, Methods and Equipment. (Conclusion.)** FRANCIS L. PETTINGIL, *Organic Finishing*, **7**, 37-41 (1946) July.

Airless blast cleaning plus its advantages.—B.L.R.

**Chemistry and Mechanism of Steel Pickling. (Continued.)** BRIAN N. REAVELL, *Foundry Trade J.*, **79**, 247-251 (1946) July 4.

Continuous pickling; ancillary plant, acid storage and acid handling; acid heating; acid neutralizing and acid recovery; materials of construction.—B.L.R.

**Surface Preparation Practices for Finishing Aluminum. art I.** ARTHUR P. SCHULZE, *Organic Finishing*, **7**, 9-17 (1946) July.

Considers mechanical methods; solvent degreasing.—B.L.R.

**New Continuous Spray Machine for Cleaning and Pickling of Metal Parts.** W. W. CLARKE, *Enamelist*, **23**, 5-9 (1946) July.

Gives description of machine; schedule of operations; shows times in the various cycles are very much shorter than is the case with the usual type of immersion cleaning and pickling, yet cleaning results obtained are much superior.—B.L.R.

**Abstracts of Organic Finishing Papers Presented at the 33rd Annual Convention of the American Electroplaters' Society.** V. M. DARSEY, *Organic Finishing*, **7**, 23-25 (1946) July.

The effect of surface preparation on the durability of organic coatings; a strippable spray-type coating; resins of the vinyl family in metal finishing; characteristics of certain plastic films and coatings.—B.L.R.

**Method of Evaluating Alkali Cleaners.** CLAUDIUS NIELSEN, Organic Finishing, **7**, 9-13 (1946) Aug.

Method given can be relied upon to give accurate predictions of results to be expected in practical applications. Makes use of a grade of paraffin oil that is available any place, and of simple and easily procured equipment.—B.L.R.

**Scientific Evaluation of Metal Cleaners.** Steel, **119**, 72-74, 106 (1946) Aug. 12.

Positive methods for determining when metal surfaces are chemically clean: water-break method; fluorescent oil method; cleaning method; spray pattern method.—B.L.R.

**Sodium Hydride Descaling and Desanding of Ferrous Castings and Forgings.** Western Metals, **4**, 35-36 (1946) July.

Operational procedure given.—B.L.R.

**Electrolytic Polishing and Its Applicability in the Preparation of Metallographic Specimens.** E. LOWGREN AND G. HILDEBRAND, *Jernkontorets Annaler*, **126**, No. 4, 131-142 (1942).

Data on a variant of De Sy and Haemers' method of electropolishing, as applied at the laboratories of Fagersta (Sweden) steel works are given, and the apparatus described. Electrolyte, current density, bath temperature, importance of agitation of bath, treatment of specimens preparatory to electropolishing, time required, and examples of applica-

bility of method are discussed. Steels and stainless steels are mentioned in most of the topics. Photomicrographs give some typical examples (including steels, stainless steels, and 18-8) of the applicability of electrolytic polishing for the purpose of metallography. Eight ref.

**Surface Condition and Passivation.** L. GUITTON, Paper before Subcomm. of Corrosion, March 15, 1945. (Commission Technique des Etats et Proprietes de Surface des Metaux) *Metaux, Corrosion-Usure*, **20**, No. 237, 68-69 (1945) May (In French).

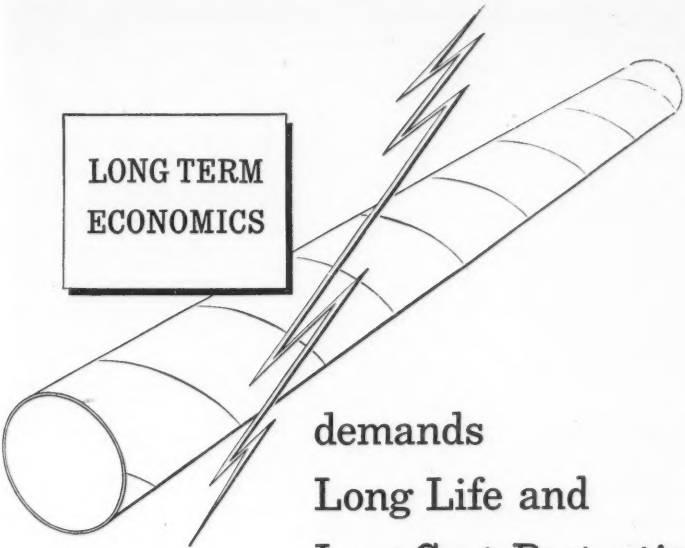
Discussion of the surface conditions and passivation of steels and stainless steels, including 18-8.

## WATER CORROSION

**Control of Fouling Organisms in Fresh and Salt-Water Circuits.** J. G. DOBSON, WALLACE AND TIERNAN, Paper before ASME, Ann. Mtg., N. Y., Nov. 26-29, 1945; *Trans. ASME* **68**, No. 3, 247-265 (1946) Apr.

Condensation of extensive and scattered information on the organisms and their control, with extensive bibliography of 106 references. Discussion includes remarks by F. L. LaQue on use of Admiralty brass, 70:30 copper-nickel and stainless steel. Use of antifouling paints, use of poisoning chemicals, creation of anaerobic conditions in the water and chlorination are discussed among other control methods. The latter is considered the best. Work by the Wm. F. Clapp Laboratories and at Woods' Hole is mentioned.





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**Corrosion of Galvanized Hot Water Storage Tanks.** J. M. BIALOSKY, J. of the Amer. Water Works Assn., **38**, 1012-1017; discussion, p. 1017-1020 (1946) Sept.

Discusses factors which can be controlled by the manufacturer and those which cannot, and gives recommendations for obtaining maximum service life. 11 ref.—B.L.R.

**Failures of Domestic Hot Water Storage Tanks.** CHARLES P. HOOVER, J. of the Amer. Water Works Assn., **38**, 1005-1011 (1946) Sept.

Discusses experimental corrosion control work and gives general conclusions. Also discusses the various protection methods and contributing causes of failures.—B.L.R.

**Condenser Tubes of Aluminum Alloys.** R. B. MEARS, Aluminum Co. of America. Corrosion, **2**, 165-73 (1946) Sept.

The corrosion susceptibility of aluminum alloy 2S and 3S and, particularly, Alclad 3S condenser tubing is discussed. They have been successfully used with certain cooling waters highly corrosive to other non-ferrous and iron alloys. Alclad 3S is comparable to seamless steel in cost per linear foot. Recommendations are made as to the control of galvanic corrosion at junctures of the tubing with structures of other metals. Since aluminum alloy mechanical strength decreases rather rapidly above 300° F., their use, except as liners for steel tubes, is not recommended above 500-600° F. Mechanical properties of various grades of aluminum alloy tubing are tabulated.

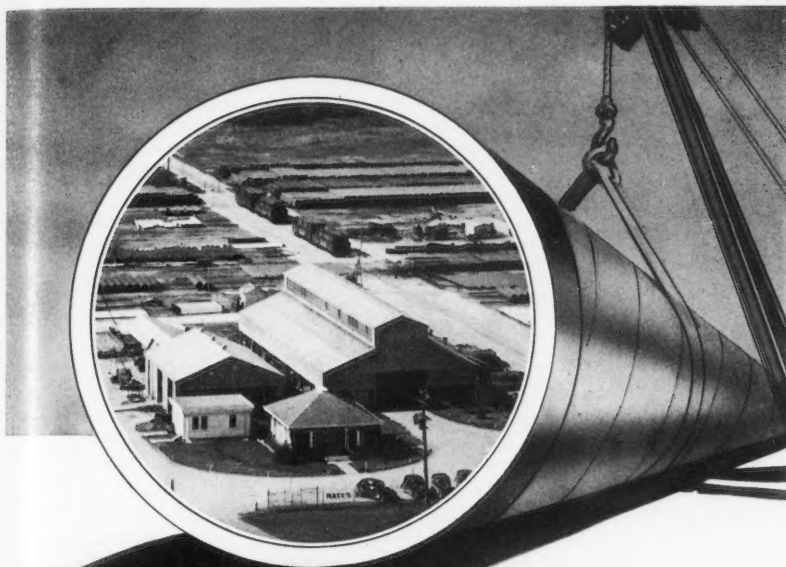
**New Stress Corrosion Control Methods.** Oil and Gas. J. **45**, No. 17, 119-20 (1946) Aug. 31.

Illinois Institute of Technology has reported new stress corrosion control methods which include a chemical solution derived from coal tar which inhibits cracking even after it has started, and the high temperature treatment of fabricated steel with hydrogen, which removes corrosion stimulating nitrogen from the metal surface.

**Transformation of Iron by Bacteria in Water.** R. L. STARKEY, J. of Am. W. W. Assoc., **37**, 963-984 (1945) Oct.; Corr. & Mat. Prot., **3**, No. 1, 27-28 (1946) Jan.

Describes the bacteria found in water. Iron bacteria are fouling organisms and not agents of corrosion. It sometimes happens that surface of fouled metal shows evidences of corrosion, but it is probable corrosion was caused only indirectly by the iron bacteria. Where water in iron pipes and conduit contains sulphide, or where sulphide is produced as in sewage, and pipe is only partly filled so that there is an air blanket over the water, some of the sulphide dissolves in the moisture film on upper walls of the pipe. Here it undergoes oxidation, due to sulfur bacteria, and the sulfuric acid formed attacks the pipe. Under certain soil conditions, exterior of pipes may be attacked by anaerobic corrosion, but little consideration as yet has been given to the possibility that this corrosion is a factor on the inside surface of water pipes.

**Design and Performance of Water Tube Condensers.** A. C. BUREAU, Gas Times, **45**, Suppl., II-VIII (1945)



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**Complete Reconditioning  
Service for Old Pipe**



**MAYES BROS., INC.**

**HOUSTON, TEXAS**

Nov. 24; *Corr. & Mat. Prot.*, **3**, No. 326 (1946) Mar.

Pays brief attention to effect of corrosiveness of water on the construction and operation of a condenser. Cast iron construction may prove to be more economical over a long period, with very corrosive water. If water is aerated, temperature should be kept rather low to minimize corrosion.

**Noncorroding Water Heaters.** *Business Week*, No. 875, 47-48 (1946) June 8.

Because electrolytic corrosion, particularly in acid-charged water areas, will attack even special alloy hot-water tanks, the McGraw Electric Co. (Chic.) has perfected the "Ionodic" system for the new Clark electric water heaters. A rod of pure magnesium is inserted into the steel tank, and in the presence of water forms a galvanic battery. The current produced causes the magnesium to go into solution and protect the steel. Although the basic principle is not new, this development incorporates a resistance between the magnesium and steel to limit current flow and retard the rate at which the magnesium is consumed.

**Sodium Hexametaphosphate as a Corrosion Inhibitor for Ottawa Tap Water.** M. COHEN, Nat. Research Council, Ottawa, Paper before Electrochem. Soc., 89th Gen. Mtg., Birmingham, April 11-13, 1946; *Electrochem. Soc.*, Preprint **89-17**, 193-207 (1946).

A study of sodium hexametaphosphate as a corrosion inhibitor for Ottawa tap water was made by laboratory test methods. For best inhibition 50 to 60 ppm (with motion

of solution) were required. Steel used for test panels was low carbon, bright, cold rolled auto body steel.

**Pipe Corrosion Caused by Air Lift.** L. R. SOWERBY, *Water & Sewage*, **84**, 15-16 (1946) Jan.; *Corr. & Mat. Prot.*, **3**, No. 4, 24 (1946) Apr.

Describes experiences at Winnipeg in connection with deterioration of well discharge pipe.

**Corrosion of Copper and Copper-Base Alloys in Fresh Water.** C. L. BULOW, J. New England Water Works Assoc., **59**, 163-182 (1945); *J. Inst. of Met. & Metall. Abs.*, **13**, 51-52 (1946) Feb.

Precipitating scales as calcium carbonate produces a coating which frequently retards corrosion. Use of Langelier's saturation pH makes possible a determination of water behavior that might result in scale deposition. Bacteria growing on pipe walls contribute toward increased corrosion owing to the creation of acid by-products in their life processes. Copper and copper base alloys rarely develop the odors characteristic of ferrous materials. Ammonia and chlorine, while beneficial in water purification, may be objectionable from the corrosion standpoint. Galvanic corrosion is not usually significant, and the rate of corrosion depends upon the relative size of anodic and cathodic surfaces, the total oxygen pick-up varying with the size of the cathodic area. Films produced by corrosion products may by either protective or non-protective. Corrosion as a rule increases with temperature. The effect of chemical changes under various conditions is discussed thoroughly with illustrations.



Thousands of tests, under all kinds of service conditions, prove that "Dutch Boy" Red Lead gives metal extra protection

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Red Lead has been long accepted as the "standard" metal protective paint. One important reason is its marked ability to stand up against moisture, a powerful factor in the rusting process.

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**2. Red Lead resists passage of moisture**—Rusting of metal will not take place if water does not penetrate the paint film to reach the metal. Water permeability tests of paint films show, beyond question, that Red Lead is one of the most effective metal protective pigments, because of its stubborn resistance to the passage of moisture through the film.

**3. Red Lead resists solution by water**—The action of water on paint films results in a partial dissolving of the film. Many metal protective films lose a considerable percentage by weight of their films through solution in water. On the other hand, the solubility losses of Red Lead paint films are practically negligible.

**4. Red Lead resists distortion by water**—Red Lead films have little tendency to shrivel, or change in size, during immersion in water. This is imperative to good metal protection. For good protection depends on good adhesion, and a paint film maintains better adhesion when it is not distorted by the action of the water.

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**RED LEAD**

**On the Influence of Surface Treatment of Pure and Super-Pure Aluminum Components, with Special Reference to Water Pipes.** H. WOLF AND H. NEUNZIG, *Aluminum*, **26**, No. 1, 17-22 (1944); *J. Inst. of Met. & Metall. Abs.*, **13**, 11 (1946) Jan.

Tubes of pure and super-pure aluminum were treated by various commercial protective processes, and by pickling for various times and at different temperatures in 10 percent caustic soda. They were then subjected for periods of 8-12 months to running water. Results of the exposure to water are given in full and illustrated by photographs. The influence of the various protective treatments is discussed. The purity of the aluminum is without marked effect.

**Fuel Economy Discussions, VI.** W. MURRAY, *Chemical Age*, **53**, 215-219 (1945) Sept. 8; *The Metal Review*, **18**, No. 11, 9 (1945) Nov.

Inhibition of corrosion of metal in contact with water or steam. Electrolytic corrosion theory; typical examples of corrosion; examples of successful inhibition; present water treatment practice; and possible future developments, are given.

**Total-Immersion Apparatus.** M. COHEN (National Research Council, Canada), discussion before *Electrochem. Soc. Steel*, **118**, No. 2, 106 (1946) Jan. 14.

Evaluation of either solution or metal is feasible with a recently developed accelerated total-immersion corrosion test. A wide latitude of conditions is obtainable with apparatus described and drawn. Preparation of a specimen for the test is also

covered. Results are of a magnitude and reproducibility sufficient for most corrosion measurements.

**Observations on the Use of Cyclohexylamine in Steam-Heating Systems.** A. A. BERK (Bur. Mines R.I. 3754) (June, 1944) (Bur. Mines Washington 25, D.C.), *Gratis.* (TA-467, M-66).

Studies on the use of cyclohexylamine in steam-heating systems to reduce corrosion are reported. These show that this amine is an effective corrosion inhibitor, but expensive, due to excessive losses of this volatile compound. It is believed that this disadvantage can be overcome by finding a less volatile amine having the same desirable properties.

**Sodium Chromate as a Corrosion Inhibitor in Gas-Condensate Wells.** Part 2. C. K. EILERTS, H. A. CARLSON, R. V. SMITH, F. G. ARCHER AND V. L. BARR, *Oil Wkly.* **123**, 30 (1946) Oct. 7.

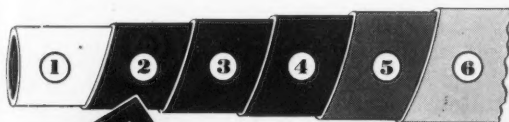
The possible explanations for the obstructions in the pipe reported in Part 1 are discussed. Either the sodium chromate is reduced to chromic hydroxide or it is merely deposited due to super-saturation of the solution. Further tests on wells are reported. The tests at the well in the Cotton Valley field proved that sticks of a corrosion-inhibiting material can be dropped into the tubing while a well is flowing. Many improvements, however, will be necessary to make the method of treatment a practical one. The wellhead magazine can be modified to simplify the method of injecting the material, and the sticks should be made longer than those used in the test so that they will be less likely to lodge in the Christmas tree when



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- \* (2) Mechanical priming with desired primer.
- (3) Hot application of desired coating.
- (4) Hot application of desired coating.
- (5) One spiral wrapping of desired wrapping material.
- (6) One spiral wrapping of heavy kraft paper.



**SPECIFICATION  
"B"**

### INCLUDES

- (1) Mechanical cleaning.
- \* (2) Mechanical priming with desired primer.
- (3) Hot application of desired coating.
- (4) Hot application of desired coating.
- (5) One spiral wrapping of desired wrapping material.
- (6) Hot application of desired coating.
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\*Primer not required with No-Ox-Id coatings.

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released from the magazine. Also, an obstruction can be placed in the tubing to catch and hold the sticks at a level where there is certain to be condensed water to dissolve them. The sticks should be coated or impregnated with sodium silicate or other material, so that some of the sticks will dissolve quickly and the solution of others delayed for several hours. The initial tests of this method of treating wells gave promising results, and additional development work is in progress.

#### **Permian Basin Fights Corrosion.**

G. WEBER, *Oil and Gas J.* **45**, 76-77 (1946) Sept. 14.

In attempting to deepen wells producing from three sands it was found that corrosion above the gas-oil contact severely indicating serious corrosion in other wells in the field, the company adopted measures to remedy the damage already done and to prevent its continuing. All wells showing casing leaks are being lined with 5½-inch casing. Then, following a practice adopted in the Magnolia field of South Arkansas, a production packer is set near the bottom of the tubing string, and the annulus between tubing and casing is filled with sweet, refined gas oil. The same program, except for lining of the 7-inch casing, is followed for wells not yet showing casing leaks. Whether caused by chemical or electrolytic action, corrosion will be halted by the static oil column. At first crude oil was used to fill the annulus but since such oil is sour and contains as much as 1 percent of water, it would require treating before being considered entirely safe for such use. The small additional

cost of gas oil was considered worth the complete protection it affords. A total of 14 flowing wells at Hobbs have been reworked in this manner, and the company has scheduled 8 more for immediate attention. In addition key wells throughout the field which are flowing at high gas-oil ratios and making water are being calipered, and if it is indicated that corrosion justifies remedial work, it will be undertaken. On the basis of what was learned at Hobbs, the company is investigating wells in other fields. Corrosion of tanks in the same fields is also discussed. Aluminized steel tanks have been found resistant to sour crudes for 2 years.

**Notch Effects in High-Strength, Aluminum-Alloy Spar Caps.** D. L. MOSELEY, J. of the Aeronautical Sciences, **13**, 397-401 (1946) Aug.

Three spar cap configurations were investigated for the effects of stress concentrations caused by large bolt holes in 14ST and 75ST spar caps. Gives test results and conclusions.—B.L.R.

**Causes and Prevention of Intergranular Fracture in Cast Steel.** C. H. LORIG, *Electric Furnace Steel Proceedings AIME*, **3**, 234-240; discussion, p. 240-251 (1945).

Discusses precipitation of aluminum nitride: prevention of intergranular fracture; time-temperature effects; ferrite precipitation; type II inclusions. Prime causes found were aluminum nitride precipitation at primary grain boundaries and ferrite precipitation as a network on the primary grain boundaries. —B.L.R.

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**Some Stress-Corrosion Studies on Austenitic Cast Irons.** J. B. URBAN, J. W. BOLTON AND A. J. SMITH, *Trans., ASME*, **68**, 633-636 (1946) Aug.

Experimentation is the most adequate approach to stress-corrosion problems and should involve various mechanical loadings of a material under corrosive conditions. When corrosive conditions are held constant in respect to concentration and temperature, useful threshold stresses if existent can be ascertained and suitable safety factors adopted. The procedure for studying austenitic cast irons on this basis is discussed, the investigation indicating that at very high stresses, such irons are subject to stress corrosion in strong hot caustic. However, threshold stresses have been found to be relatively high, markedly exceeding stresses contemplated in design and application. Thus the desirable properties of such material can be utilized to good advantage, with margin to assure adequate safety in this corrosive medium.—G.P.C.

**Metallurgy and the Oil Industry.** Part 1. Metallurgical Specifications. G. R. INGELS, *Oil Wkly.*, **123**, No. 3, 168-69, 172 (1946) Sept. 16.

The importance of adequate metallurgical specifications in the petroleum industry is cited and the need for care when writing such specifications with regard to proper macrostructure, hardenability and microstructure is stressed. Photographs of the macro- and microstructures of various steels are included.

**Graphitization in Some Cast Steels.** A. J. SMITH, J. B. URBAN AND J. W. BOLTON, *Trans., ASME*, **68**, 609-624 (1946) Aug.

Field service and controlled laboratory experiments have demonstrated that it is not possible to insure against graphitization of carbon molybdenum steel through any of the controlled procedures of melting and deoxidation practice or heat treatment. It is probable that freedom from graphitization is to be sought through the use of alloy additions which confer greater stability to the carbide. A hypothesis has been put forth concerning the mode of graphitization based upon the observed graphitization behavior of both plain-carbon and carbon-moly steels. Use has been made of this hypothesis to explain the resistance to graphitization of the nickel-chrome-moly steels. The experimental evidence would appear to indicate that the hypothesis is substantially correct.—G.P.C.

Editor's note: Abbreviations at the end of abstracts indicate contributing organizations as follows: B.L.R. Battelle Library Revue; I.N.C. International Nickel Company; G.P.C., General Petroleum Corporation. This is in line with the program now under way through the cooperation of the American Coordinating Committee on Corrosion and the National Association of Corrosion Engineers. When the program is completely organized, a code listing the contributing organizations will be printed.

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